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PASSIVE SOLUTIONS FOR COOLING AND HEATING LOADS OF MODERN HOUSE IN TRIPOLI

Case Study Climate-Conscious Prototype using CAD and Other Modelling Tools.

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ABSTRACT

The underlying links between culture, climate and buildings, ignored in recent times, has led to buildings with poor regional responses. This study investigates within the distinctive cultural and climatic conditions of Tripoli paradigm for the design and construction of modern dwellings where the thermal performance is such that indoor comfort, which is compatible with the cultural context in summer and winter, is minimally reliant on "active" cooling or heating aids.

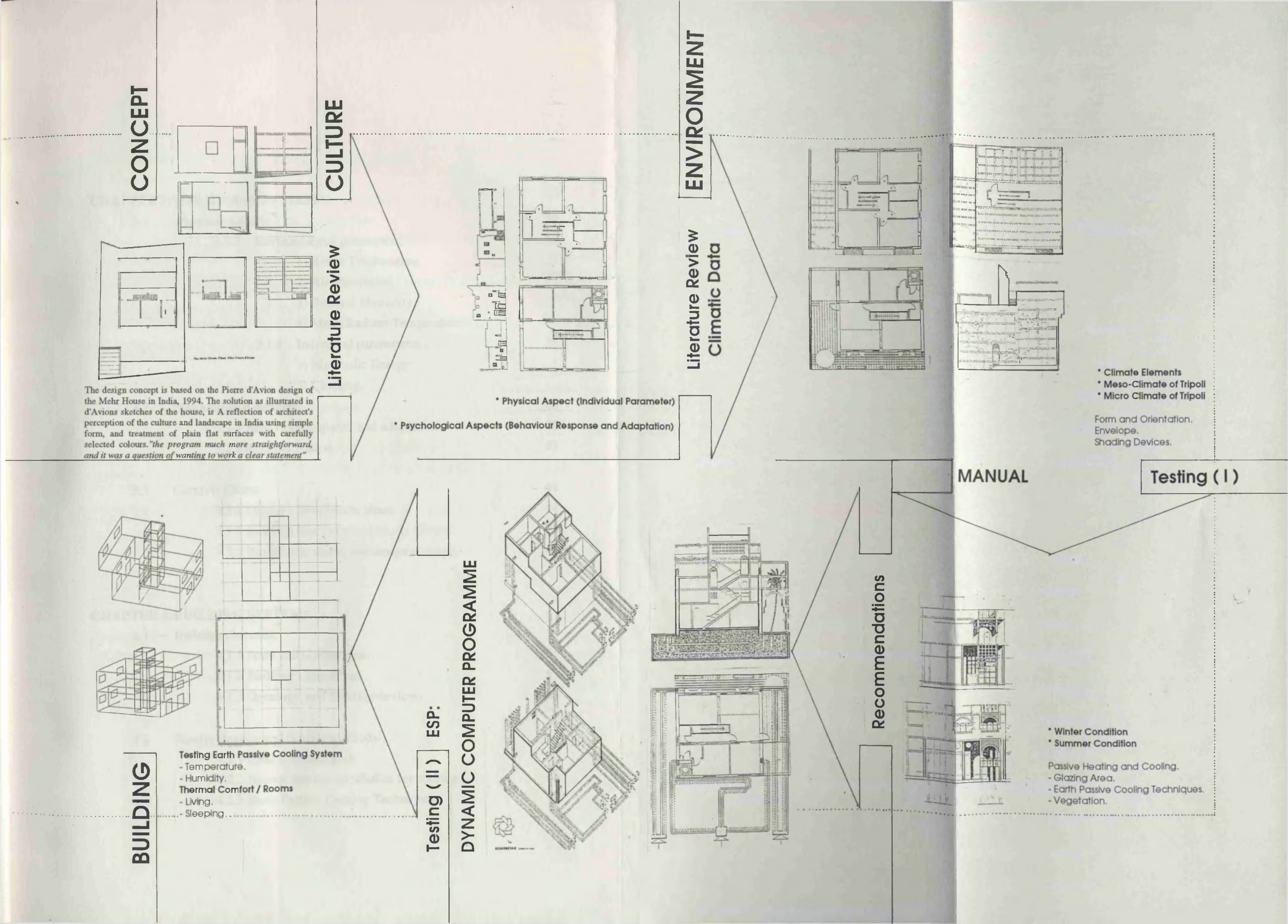
A number of predictive techniques have been used. These range from the sophisticated dynamic thermal modelling of Environmental Systems Performance (ESP), to manual calculations, that explore particular components such as walls and roofs as well as the building as a whole.

A prototype design has been developed, with a north-south orientation, two rooms deep and with a relatively narrow frontage. The design promotes both cross-ventilation and stack ventilation, a central stairwell assisting in the latter, while a system of earth cooling with passive dehumidification is envisaged for the air supply during the hottest summer period. This design has been modelled and simulated using ESP.

The conclusion confirms that the energy demands for a modern type of house in Tripoli can be minimized through its design, which take due account of religious. social, and local architecture features as well as indicating the potential for passive techniques.

a) The use of the earth's temperature for cooling the house through earth tubes has a positive effect on thermal comfort during the peak hours of summer days; while night cross ventilation is also effective.

b) In winter the use of solar radiation for space heating, through relatively large south facing windows can achieve comfort during the day while the insulated construction provides sufficient damping and time lag to minimize the effect of night losses.


CONCEPT
CULTURE
Literature Review
The design concept is based on the Pierre d'Avion design of the Mehr House in India, 1994. The solution as illustrated in d'Avions sketches of the house, is A reflection of architect's perception of the culture and landscape in India using simple form, and treatment of plain flat surfaces with carefully selected colours. "the program much more straightforward, and it was a question of wanting to work a clear statement"
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I would like to dedicate this work to my loving mother and father for their moral support and to my adoring daughter Fadwa.

1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 LIBYA, THE NATIONAL PROFILE.

The state of Libya came into being after World War II. It occupies an area of land located in north Africa between 39 40 N,. 25 10 E to 19N 24 00E, Figure (1). It is bounded on the north by the Mediterranean sea, on the east by Egypt and Sudan, on the south and south east Chad and Niger, on the west by Algeria and on the Northwest by Tunisia. It is the fourth largest country in Africa with an area of 1760,500 sq. km.

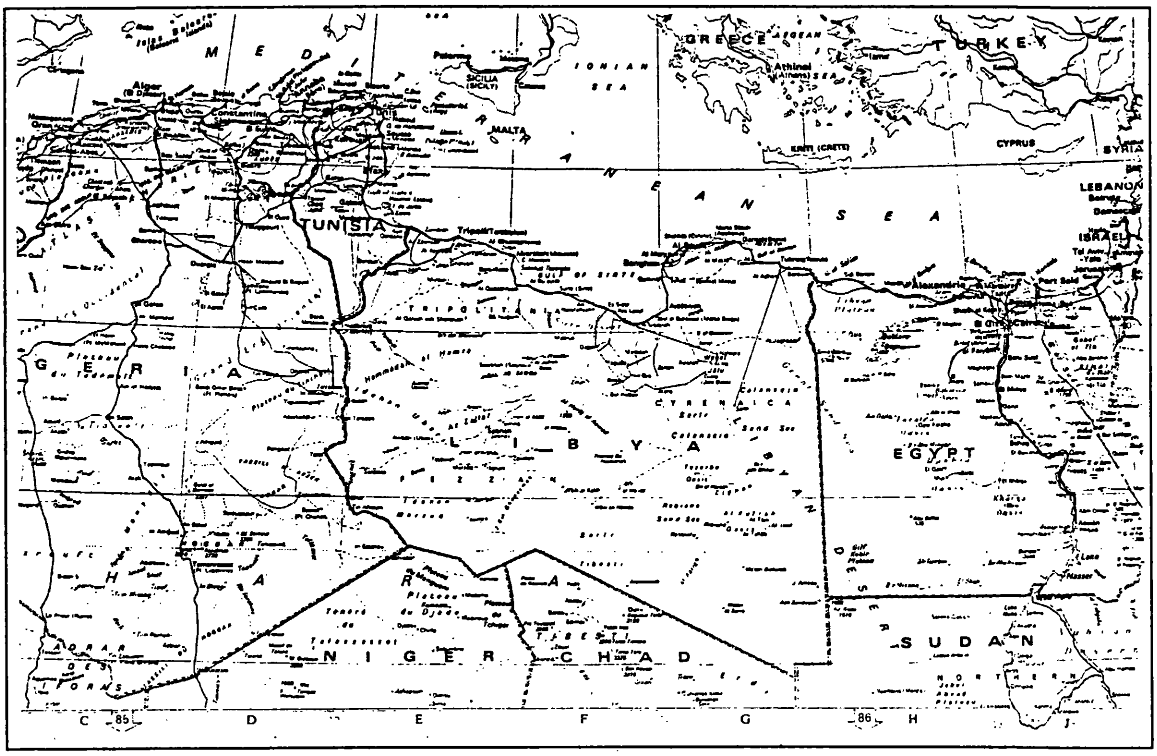

Figure (1), Libya and its location in North Africa

The country is divided into four provinces, the western province "Tripolitania", the eastern province "Cyrenaica", and two southern provinces "Fazzan" located in the Southwest "Elkhalij" in the Southeast.

In the provisional census of 1984, the country's estimated population was 3,637,488 (The Middle East and North Africa, 1989: 645). This is distributed unevenly as result of its physical features with 90% of the land uninhabitable, being mainly desert (Sahara). The remaining 10% contains about 90% of the population located along the coastal area in two main regions, the Western province which has about 65 % of the population and the Eastern province about 25%. Libya has a population growth rate of about 3.8 % per year, with almost 44% under 14 years of age and 51 % between 15 to 65, and only 5% over 65 years of age.

1.2 HISTORICAL AND ECONOMIC BACKGROUND

Libya like any other North African Arab country has had a long history of subjugation by foreign powers and influences, beginning with the Phoenician, Greek and the Roman empires, extending, to the Turks and Italian colonisation. Independence was proclaimed in December 1951. Before that date, following the conquest of the Italians, Tripolitania, and Cyrenaica had been ruled by a British administration, and the Fezzan was administered by France. As a result of these interactions, the country has been remarkably influenced in all areas, but particularly in its architectural heritage. This is clearly marked by the Architecture in major cities such as Tripoli and Benghazi.

In 1959 after the discovery of oil occurred, the nation faced great changes and extensive widespread development. The fostering of industries which produced consumer goods, reorganised town planning and improvement of housing conditions, roads, telecommunications, electricity, and water supply.

The Libyan economy is now dependent on oil and gas for its source of income. Also, throughout the last decade a number of industries have been developed, most of which are based on oil, such as the petro-chemical industries, iron and steel production and some light industries.

Since the discovery of oil, Libya has enjoyed a high national income and benefited of a cheap source of energy both for industry, domestic and commercial use. Continued stable and low cost energy has led the population as a whole to be careless both with consumption of energy particularly electricity, and neglectful of the consequences of pollution. Cheap electricity coupled to improved living standards and expectations has resulted in an increase in energy demand from 40 million GJ in 1965 to 270 million GJ in 1986, and it is projected to reach 1400 millions GJ in the year 2010 (CSES, Report, 1991) Figures (2) and (3).

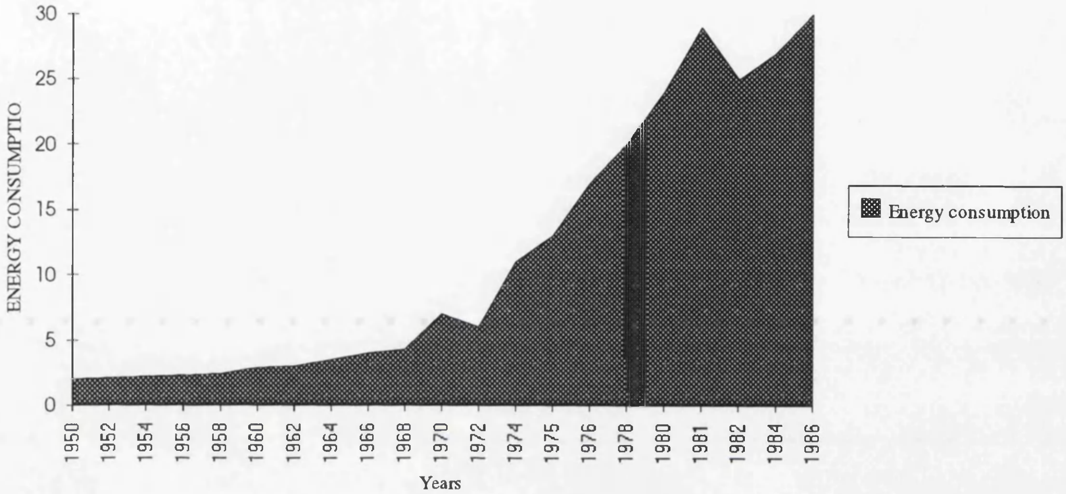

Figure (2) Fossil Energy Consumption versus Time. Source CSES Report, 1991: p.3

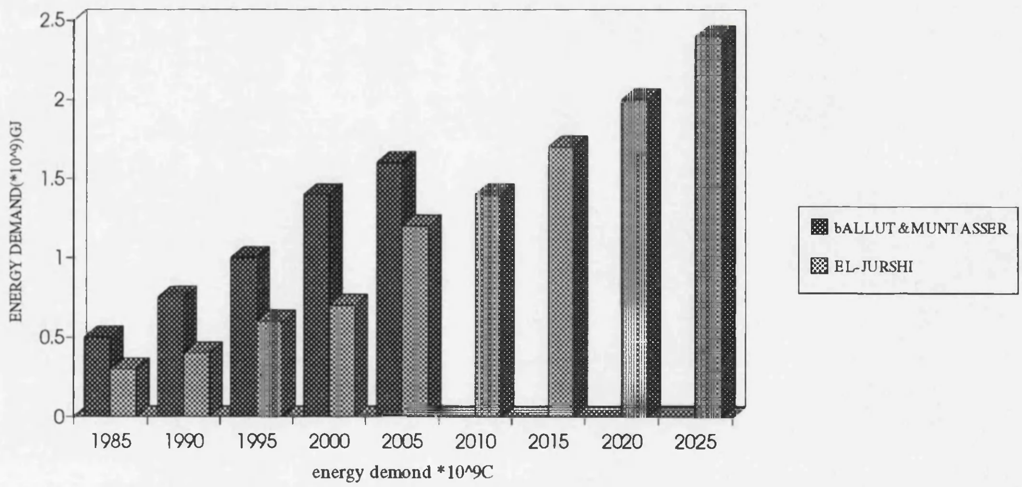

Figure (3) Energy Demand Projections versus time

In the search for an alternative source of energy, the Government has established a Centre for Solar Energy Studies (CSES). It's objective is to promote and direct solar and wind energy research and demonstrate how the output of research work could be incorporated into construction projects. The first solar building is to be built in Tripoli as an experimental model. The aim of the model is to provide a departure point, as reported by CSES (1991, p5) for:

1) The utilisation of solar energy will be a design requirement in which energy conservation in the housing sector can be achieved.

2) Strategic and simplified design guidelines can be determined.

3) CAD evaluation of thermal performance can be applied

1.3 ENVIRONMENTAL PROFILE

1.3.1) Topography

The western border of Libya is 1100 km long lying next to Tunisia and Algeria. The eastern border is 1400 km long lying next to Egypt and Sudan. The Northern border is formed by the Mediterranean Sea and is 1950 km in length. Libya consists of a number of topographic areas with different soil characteristics. Thus, each region can be divided into several sub-regions. However, the three significant topographic regions which concern this study are illustrated in Figure (4)

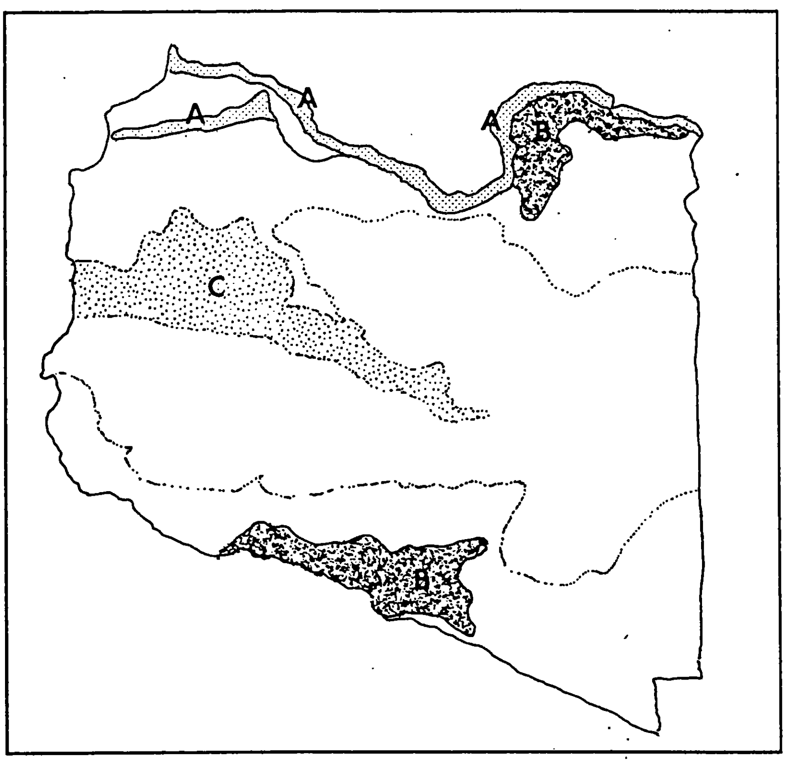

Figure (4), Principal Topographic Regions of Libya: A) The North Coast and Jefara Plain B) The Mountains (the high land) c) The Sahara Desert

a) The north coast and Jefara plain, This is the most recognisable region, which extends from the East to the West of the country. Its width ranges from 3km to 100km, narrowing close to the "Al-Jebal Al-Akhdar" (the green mountain) and expanding to 100km width before "Jebal Nafusa" (the western mountain). This area is associated with the greatest cultivation in the country. Apart from the Gulf of Sirt, where the coastal region projects far into the desert, this coastal strip is the richest of all regions in water and fertility, and is the most densely populated. In the Jefara coastal sub-region, the land slopes toward the sea ranging in height from 200m to 300m near the mountains down to 20m close to Tripoli. Other parts are more level and in some cases merge with the desert .

b)The mountains(the high land). This area is divided into two main mountains. First, there is the western part, to the south of the Jefara Plain where it rises steeply above Jefara. Its average width is being around 20 km, extending towards the east about 400 km from the Tunisian border to 110 km west of Tripoli and containing a high range of hills from 500 m to 960 m high. These mountains are associated with old olive trees, which cover many mountains and valleys. Moreover, the land is composed of basalt, volcanic rock, limestone-loess and gypsum-marl. On its south edge exists red stone desert.

The second part is the eastern mountain Al Jabal Al Akhdar, which has heights ranging between 300m to 830 m, and rising steeply extends along the eastern coast. This area also consists of limestone, calcareous, sand stones, marl and red soil, while the mountain is covered with scrub forest consisting of pine, carob, acacia, and juniper bushes.

c)The Sahara desert, This part begins just south of the Gulf of Sirt, an area from which the two mountain regions rise up towards the east and west of Libya. The desert is the dominant part in terms of area, as it covers about 90% of the country. It is an isolated area, with hills ranging from 700 to 1.000 m in height. There are number of oases situated in shallow basins and valleys, where ground water reaches the surface forming natural springs. Palm trees form the vegetation of the Oasis, and the foundation land is limestone, sand stone, gypsum and fine sand hills. Most of the desert contains unstable sand which migrates from one place to another.

1.3.2) Macro Climate of The Country:

The climate of Libya is characterised by its aridity and by its wide variation in temperature. As a result of its location and the lack of high mountains' barriers, the country is open to the influences of both, the Sahara desert and the Mediterranean sea.

Temperature, also varies from one part of the country to another. In winter, it can be fairly low and cold in the north, with sleet and even light snow on the mountains, while in summer it is extremely hot, with temperature as high as 45°C. In addition, the size of the country extending from the Sahara to the Mediterranean causes climatic variations even in the same region, such differences also associated with the contrast between the low laying areas and the mountains. However, the climate generally can be divided into four types plus an unclassified mountain climate, as illustrated in Figure (5):

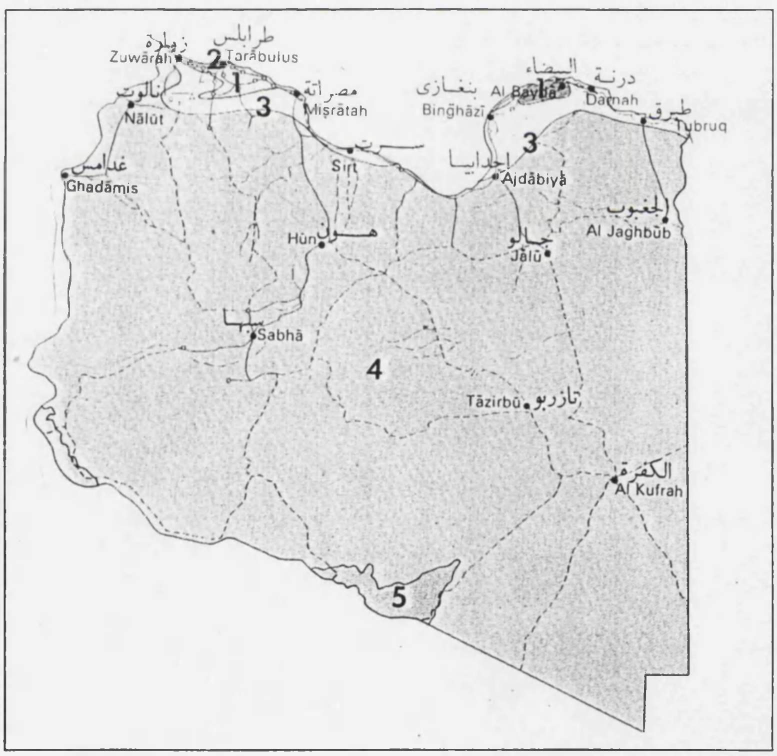

Figure (5): The general classification of Libya's climate, After Buxtehude,1981

1) Mediterranean climate-on the mountains (cold zone). 2) Semi- Mediterranean -on the coastal area (Hot -humid). 3) Steppe (Semi arid). 4) Desert (Hot-arid) 5) Unclassified mountain climate.

1.4 THE CITY OF TRIPOLI: AN OVERVIEW

Tripoli is the capital of Libya, located on 32.54 North Latitude 13.11 Longitude. The city is the largest in the country and inhabited by 56% of the total Libyan population. A significant factor of the city is derived from its strategic location on the Mediterranean. Thus, the city has experienced an influential foreign interaction. Consequently, this did not only affect the way of life, but also the urban fabric and the architecture of the city. The urban fabric of the city consists of two distinctive characteristics: the old city, where vernacular architecture dominates the image, and the modern city which represents the expansion of the city during this century. In both, a remarkable range of architectural styles has emerged.

The Old City of Tripoli, contains a unique mixture of indigenous, architecture of Turkish character, where a number of 'passive' solutions can be recognised as techniques that have been developed over generations to respond to the climate and to maintain comfort. Solutions such as courtyards, thermal storage walls, white painted surfaces, 'Mashrabia', and vegetation, are commonly found, Figure (6). In response to the rapid economic change in the modern part, which is characterised by the Italian contribution as well as many local architects, most of these systems have been abandoned and substituted with techniques relying on electricity for air-conditioning, Figure (7).

The classifications of Tripoli's climate vary from one study to another. Buchanan (Colin Bochanan and partners 1975, vol.1, p 14 -17).classified it in his studies for the National Housing Corporation in 1975 as a Hot-Humid zone, while in the modified classification by Kopper (Evance,1980) it is considered as Steppe climate. In the Atlas of Libya, Tripoli has been classified as a Semi-Mediterranean climate because of the abundant growth of Mediterranean vegetation. However, in this study, Tripoli's climate will be classified according to the G.A Atkinson classification as a Hot-dry climate associated with a subgroup of a Maritime desert climate.

It is suggested in this study that Tripoli should be the location for the proposed model of an Energy Efficient House Design. It is arguable, that due to the increasing energy demands housing should provide a sustainable low energy environment and to this end, architects particularly in Libya should consider passive techniques that make positive architects particularly in Libya should consider passive techniques that make positive use of solar energy for space heating in winter, for water heating throughout the year, that can maintain comfort, systems that provide a way to use the potential of unlimited solar and geothermal energy resources, and that can minimise its impact in summer to an extent that internal comfort is minimally reliant on mechanical aids.

Figure (6) The Old City of Tripoli

Figure (7): The Modern City of Tripoli

1.5 THERMAL ANALYSIS AS AN APPRAISAL ASPECT.

This study adopts an approach to building appraisal that requires measurement of particular aspects of thermal performance within the building, which are tested against a suitable 'yardstick', that might be the owner's or user's stated requirements, together with the architect's intentions defined by his formal instructions, drawings, specifications, or building codes and regulations. The findings of such testing would indicate the acceptability of the model.

Bishop (1978) argues that a systematic approach to building appraisal is suitable. A definition of 'system' is required, Beishon (1971, p.11), which states the criteria that identifies 'systems', as an assembly of parts or components connected together in an organised way. The particular assembly has to be identified by a human as being of special interest. The parts of the system generally, affected by being in the system, will change if they leave it. The assembly of parts may have certain a behaviour pattern which would change if the outside world does.

ENVIRONMENT SYSTEM		BUILDING SYSTEM		HUMAN SYSTEM	
CULTURAL CONTEXT	PHYSICAL CONTEXT	BUILDING TECHNOLOGY	INTERNAL AMBIENCE	USER REQUIREMENTS	CLIENT OBJECTIVES
	The site as given in terms of:	Modifications of external environment to provide suitable ambience for specified activities by means of:	Provision of physical conditions for performance of activities in terms of:	Provide for specified activities in terms of the following needs:	Return for investment in terms of:
Social Political Economic Scientific Technological Historical	*Physical characteristics:* climatic geological topographical	*Available resources in terms of:* cash materials labour/equipment		*Organic:* hunger and thirst respiration elimination activity rest	Security Prestige Profit Expansion or other provision for change
Aesthetic Religious	*Other constraints:* land use existing built forms traffic patterns legal	*Structural systems:* mass planar frame *Space separating system:* mass planar frame	*Structural mass:* visible surfaces space enclosed	*Spatial:* functional (inc. fittings) territorial *Locational:* static dynamic	Housing of particular activities so as to encourage user well-being, motivation, etc.
		Services system: environmental information transportation	*Sensory environment:* lighting, sound control heating/vent	*Sensory:* sight hearing heat and cold smell kinaesthetic equilibrium	
		Fitting system: furnishing equipment		*Social:* privacy contact	

Table.(1) Broadbent's conceptual model in which three major systems, human, building and environment are interrelated

The built environment has been defined as a system. Broadbent argues, (1973:.384), that to design a building, information on three areas is essential; the site and its indigenous climate, the pattern of activities, and the technology of building. Broadly, his concept embraces an integrative framework of 'environment', 'human', and' building'. Considering, Broadbent's interacting model, Table(1), which is based on the idea that each system forms a complete and self-interacting whole, as well as the state of integration between these systems through their sub-systems. The interaction emerges within the relationship between the respective components of the framework.

This study endeavours to explore the building as a climatic modifier, or a filter between the external environment and the user. The discussion, will limit itself to particular sub-systems of the mentioned systems that have an influence on the performance of a building thermally.

1.5.1. Environment

Climate classification as a sub-system of the environment is a critical factor in which the interaction with the other systems of building and Humans is constantly developing .This interaction emerges within the context of thermal performance. Both, the macro and micro climates will be explored.

1.5.2 Humans

The human body is a system as a whole, and through its sub-systems, it maintains balance with the environment by minor physiological changes. It is arguable that noise, light and colour levels affect human comfort. However, for the purpose of the study, the discussion will be limited to physical feelings of thermal comfort which depend on six parameters. Two of them the level of the metabolic energy and clothing are related to the individual, while the other four, temperature, relative humidity, mean radiant temperature and air velocity, are related to the environment.

1.5.3 Building

Building is the system in which a human can maintain her/his comfort- a system that is subject to an interaction between climatic characteristics and human requirements. The heating and cooling strategies are what facilitates such interaction. Building as a system will be explored at the level of thermal performance, whereby considering certain parameters a satisfactory interaction between the environment and occupant can be accomplished.

1.6 THERMAL ANALYSIS

Thermal performance is the heating or cooling necessary to maintain thermal comfort, in given conditions with respect to clothing, activity, air movement and humidity. According to the Centre for Building Performance and Diagnostics (CBPD), the minimum basis for determining total building performance are: thermal, acoustic, and visual properties, together with air conditioning, spatial comfort and the buildings integrity. From these six, thermal comfort is considered the most important from a financial point of view.

Energy crises in the 1970s with respect to oil supply, followed by a growing acknowledgement of global warming and damage to the Ozone layer in the 1980s and 1990s, together with the increase of user expectation of a building's thermal performance have forced architects to deal more carefully with this issue in their designs. However in order to design a building that requires less energy and therefore reduce costs, a careful analysis of thermal components is vital.

Historically, the norm has been for thermal analysis to be delegated to a mechanical engineering consultant and interfaced in the later stages of the design process. This has a negative effect on the design process in terms of its conceptual development. The design of a building's envelope should be integrated with the required degree of thermal comfort from inception, and refined as the design moves to a more detailed stage.

In addition, technology has increased the complexity of building design, making it nearly impossible for the architect to use experience or traditional manual techniques for an analysis of thermal performance. Recently, architects have found themselves in need of computers to aid such evaluation. The speed and flexibility that computers provide, allow analyses of many design proposals for a building in the early stages of design.

1.7 STRATEGIC RESOLVE.

A literary review of relevant studies has been conducted. It has revolved around two broad categories. Firstly, the general framework of the building's performance, considering Broadbent's interacting model based on the integrative framework of the three systems of Environment, Humans and Building. Secondly is the potential of CAD in this respect. CAD literature suggests that CAD applications in thermal performance can be useful for the early stages of architectural design.

To sum up, the core argument of the study is concerned with the examination of the thermal performance of an assumed 'Energy Efficient House Design', and its impact on user requirements in a given cultural context. This study attempts to explore the interrelationship between 'environment', 'building', and 'human' as interdependent variables.

The investigative procedure is based on an appraisal of thermal performance. A prototypical model of an energy efficient house has been designed. With the use of manual methods and a mix of small (dedicated to components such as roof and walls) and one large (dedicated to component and complete building.) dynamic computer programme, namely Environment Systems Performance (ESP), it has been tested in terms of its thermal performance in a given climate.

Structure of the Thesis.

The general framework of the study consists of three major parts:

- Chapter 2, 3, 4 review the three systems of environment, humans and building. The review is conducted from the general to the specific and from concept to application, with the climatic conditions of Tripoli, Libya having been selected for the case study.

- Chapter 5 deals with the proposed model of the energy efficient house design. The examination of the proposal has been carried out on three levels:

a)The manual method of 5000 (with space heating) and other manual routines (strategic decisions with respect to summer ventilation).

b) CAD application of "Thermal" (equivalent outside temperature profiles, give thermal damping and time-lag for specific components).

c) CAD application of ESP (shading model, full dynamic analysis of both components, including earth cooling system, and complete building.).

-Chapter 6 discusses the result of the examination, and presents the conclusion of the study within the framework of:

a)The relationship between the three adopted systems of environment, humans and building.

b)The proposed prototype as an energy efficient model using passive principles such as stack- assisted earth cooling.

c)The potential use of manual and CAD applications in the evaluation of thermal performance.

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2.0 ENVIRONMENT SYSTEM

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2.1 THE CLIMATE ELEMENTS AND CLASSIFICATION

The focus of the study is on those factors or sub-systems of the climate which have direct influence on thermal performance of a building as well as a direct interaction with other sub-systems of the building and humans. A number of different classifications of climate zones have been developed by geographers. The common factor that has been shared is that classifications have always been related to vegetation zones or the rate of precipitation and temperature. However, one of the most well known and widely used classification, is based on the vegetation that may be grown, rather than the vegetation that exists in the zone.

In relation to building needs, Atkinson's classification, (Evans, 1980: 44) of hot climate is the most commonly used. The major zones and sub-zones are distinguished according to the average monthly and annual average temperature together with the minimum and maximum monthly rainfall and annual average rainfall. It includes three main climate types, warm humid (W.H), hot dry (H.D), and composite or monsoon (C). Their sub-groups are tropical island climate, maritime desert climate and tropical upland climate.

2.2 THE CHARACTERISTICS MARITIME DESERT CLIMATE

The classification of Tripoli's climate is, according to Atkinson's classification, a maritime desert climate, which comes as a subgroup of the hot-dry climate as a result of the city's coastal location on the edge of a desert.

The result of the combination of desert and sea effect is characterized with a relatively high diurnal range in air temperature, as much as 10 K, and a relatively high humidity, averaging about 40% - 90%. The rainfall in winter (which is three months) does not normally exceed 250 mm, and summer is normally dry. The sky is clear most of the year except in the cooler season where the level of diffuse radiation is higher, and in addition to the global wind Tripoli experiences on-shore and off-shore breezes.

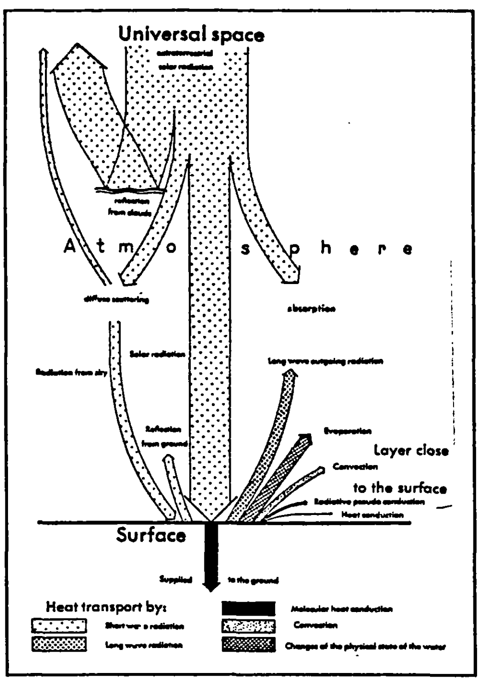
2.3 MESO-CLIMATE: TRIPOLI

Since this study is concerned with the thermal design of a building, the focus will be on the effect of the four major components of meso climate and their importance in this respect:

2.3.1 Solar radiation.

Radiation has been defined as an electromagnetic radiation emitted from the sun, (Goulding, et al, 1992: 224). Outside the Earth's atmosphere the intensity of solar radiation is approximately 1.4 kW/m2, but the actual surface of the ground level receives less solar radiation because of the series of losses that occur when the radiation passes through the earth's atmosphere.

Variation of radiation on the surface is generally caused by the location, altitude, and time, as well as the level of the site in reference to sea level, topography and amount



of cloud or haze. Radiation affects a building through five main channels, Figure(8):

Figure (8): Five channels of Solar Radiation

1. Direct short waves radiation from the sun.
2. Diffuse short wave radiation from the sky vault.
3. Short wave radiation from heated ground and nearby objects.
4. Short wave radiation reflected from the surrounding.
5. Outgoing long wave radiation exchange from buildings to sky.

Examination of the level of influence of solar radiation as a climatic component on the building requires certain data for analysis. This data is summarized as follows:

1. The sun movement pattern, location and latitude.
2. Monthly mean value of the daily duration of bright sunshine.
3. Monthly mean daily global radiation (direct and diffuse) on the horizontal.
4. The hourly mean global irradiation on a vertical or tilted sloping surface.

It may be noted that (3)and (4) can be calculated from (1) and (2), and (4) is more readily and more accurately calculated from (3), which is often measured at meteorological stations. For greatest accuracy, for example in a monitoring programme, (4) is measured on site.

2.3.2 Solar Radiation Data: Tripoli - Libya

Tripoli like other Libyan cities has a high level of insolation with the average daily solar radiation over the years 1981-1987 was about 6.948 $kWhm^{-2}$ .As a result of the lack of documentation in Tripoli little radiation data is available. However, since the information on the duration of bright sunshine throughout the month is available, the other missing data can be determined according to (Markus & Morris,1980). The radiation data that is required for analysis is as follows:

1) The location and latitude.

The city is located on 32.54 North Latitude 13.11 Longitude. Therefore it has for example, a solar altitude of 80 degrees at noon in June and 33 degrees in December. The azimuth angle of the sun (i.e. on the horizontal plane) may also be calculated for any particular time , and from this knowledge of solar geometry we can find the monthly mean daily number of hours between sunrise and sunset.

2) Monthly mean value of the daily duration of bright sunshine.

The data for the monthly mean daily duration of bright sunshine in Tripoli is available from the Libya atlas, shown in Figure(9), and ranges from 4.7 hours in December, to 9.4 hours in June.

Mean monthly duration of bright sunshine in hours per day.

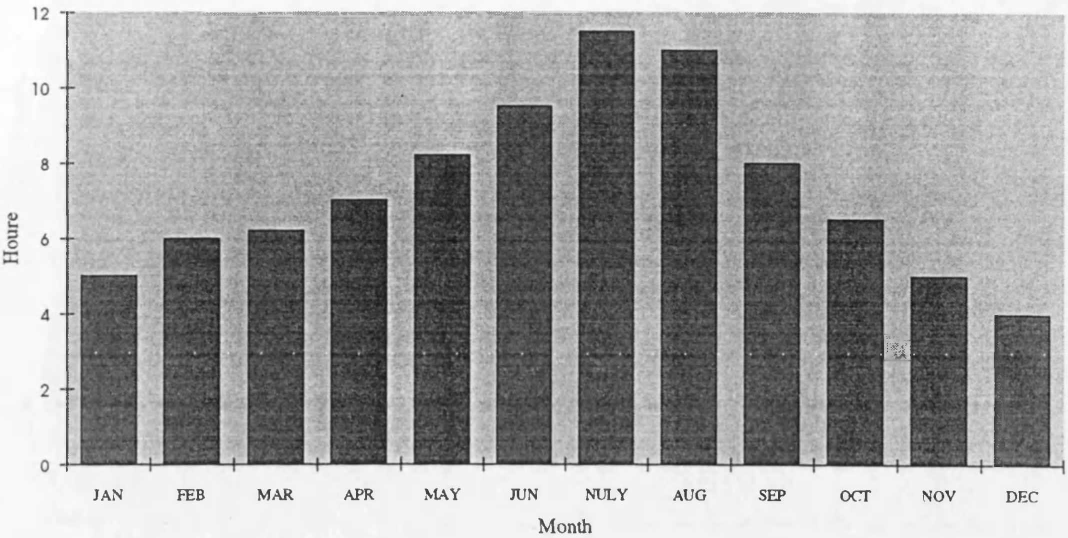


Figure (9): Bright sunshine hours per day in Tripoli

3) Monthly mean daily global radiation (direct and diffuse) on the horizontal.

The monthly mean daily global irradiation on a horizontal surface, H, is found from the bright sunshine hours by the following formula:

$$H = H_o\,[a + (bn / N_o)]$$

Where a, d = are climatically determined constants assume for Tripoli a =0.21 ,b =0.61

n = The monthly mean daily hours of bright sunshine

No= The monthly mean daily number of hours between sunrise and sunset.

Ho= The monthly mean daily global irradiation on a horizontal surface at a location above the atmosphere.

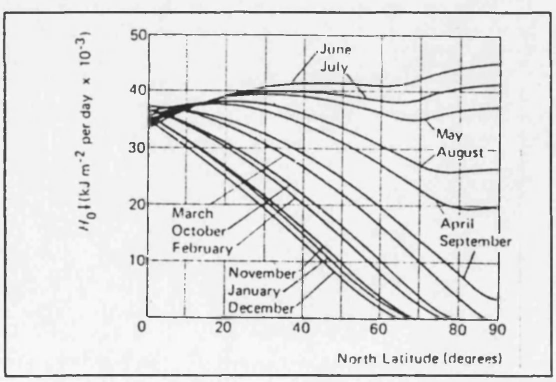


Figure (10): Values of Ho↓ at various latitudes and times of year. (after Duffie and Beckman). Markus, et al, 1980: 191

The value of Ho is determined from the chart illustrated in Figure (10) which is based on Duffie and Beckman, (Markus, et. al., 1980), and which gives values of Ho at various latitudes and time of the year.

The monthly daily diffuse radiation on horizontal surface (Hd), can be determined from the monthly mean daily global irradiation (Ho) by expressing the ratio Hd/H as a function of H/Ho see the chart based on Liu and Jordan, (Markus, et al., 1980: 191), Figure, (11). An alternative method is by the following formula.

$$H_d / H = c + d\,(H / H_o)$$

where c & d are climatically determined constants. For Tripoli c =1.07, d= -1.26

From the previous formulae the monthly mean daily global irradiation (Ho) and the monthly daily diffuse on horizontal surface has been calculated for Tripoli.

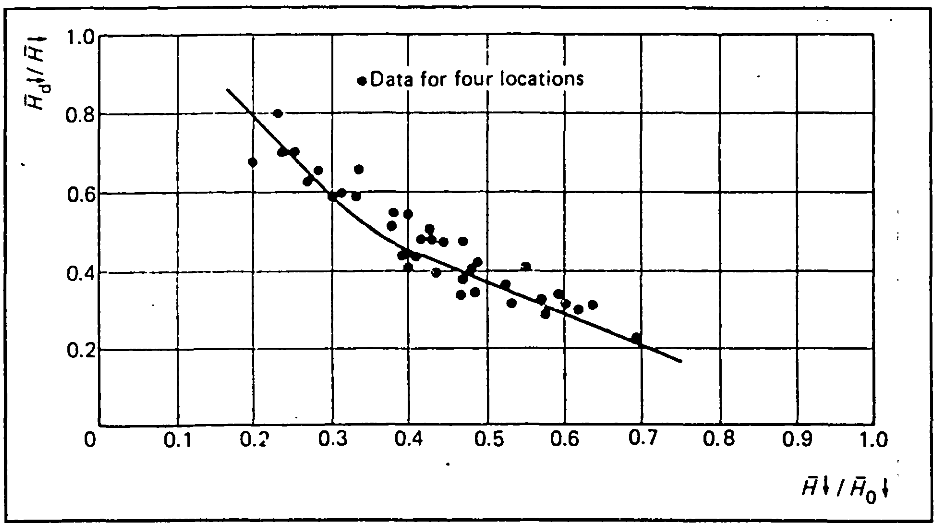


Figure (11): Estimation of diffuse irradiation Hd

4) Hourly mean global irradiation on vertical sloping surfaces (H_{Ghs}) .

As result of the sun's movement the global irradiation varies with time. Therefore this data has a significant effect on the amount of heat flow through a building.

The hourly mean global irradiation on a vertical surface (H_{ghs}), is determined by the following formula:

$$H_{Ghs} = H_{Dhs} + H_{dhs} + H_{ghs}$$

Where a): HDhs = mean hourly direct irradiation on a sloping surface,

b): Hdhs = mean hourly diffuse irradiation on a sloping surface.

c): Hghs = mean hourly ground -reflected irradiation on a sloping surface.

Therefore, we need to ascertain hourly mean global, diffuse and direct irradiation on a horizontal surface Hhg, Hhd and HhD. These can be determined by using a chart based on Lui and Jordan, and Duffie and Beckman, Figure (12), and as the number of hours from sunshine to sunset is available we can estimate the ratio of Hh mean hourly irradiation on a horizontal surface to the mean daily irradiation on a horizontal surface, for each hour throughout the day.

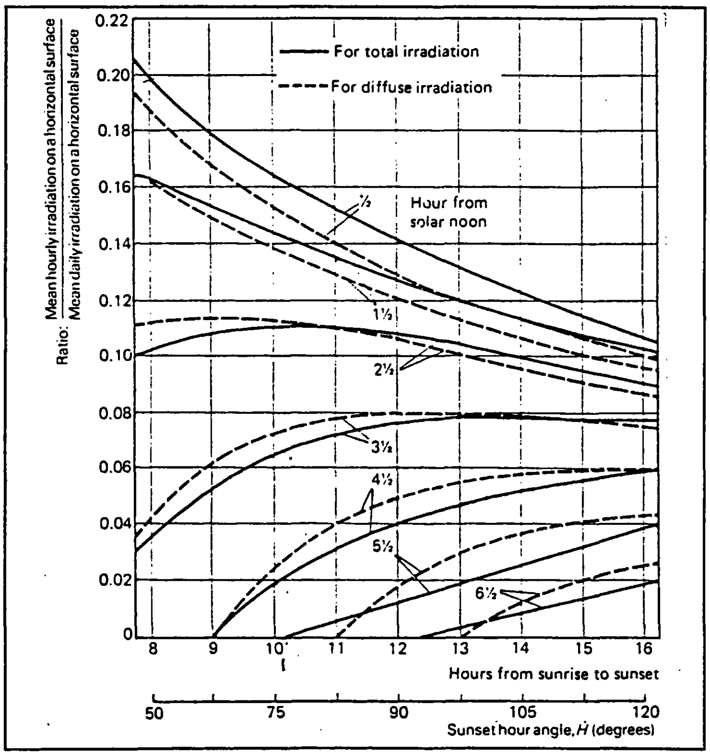


Figure (12): Estimation of hourly irradiation, (Markus, et al.,1980: 193)

a) The mean hourly direct irradiation on a sloping surface could be determined by the following formula:

H_{Dhs} = Hdh* Rh, Where, Rh= HDhs/HDh =cosi /cos z

and where-i = mean hourly incident angle of the sun on the surface, and z is the mean hourly zenith angle of sun on the surface, Figure (13.

(b)The mean hourly diffuse irradiation on a sloping surface could be determined by

H_{dhs} =H_{dh} (1+cos s)/2

where s- is the slop a angle of the surface from the horizontal.

(c) The mean hourly ground reflected irradiation on sloping surface H_{ghs} can be determined by:

H_{ghs} = r H_h (1-cos s)/2

where r = the ground reflected factor.(Tripoli =0.2)

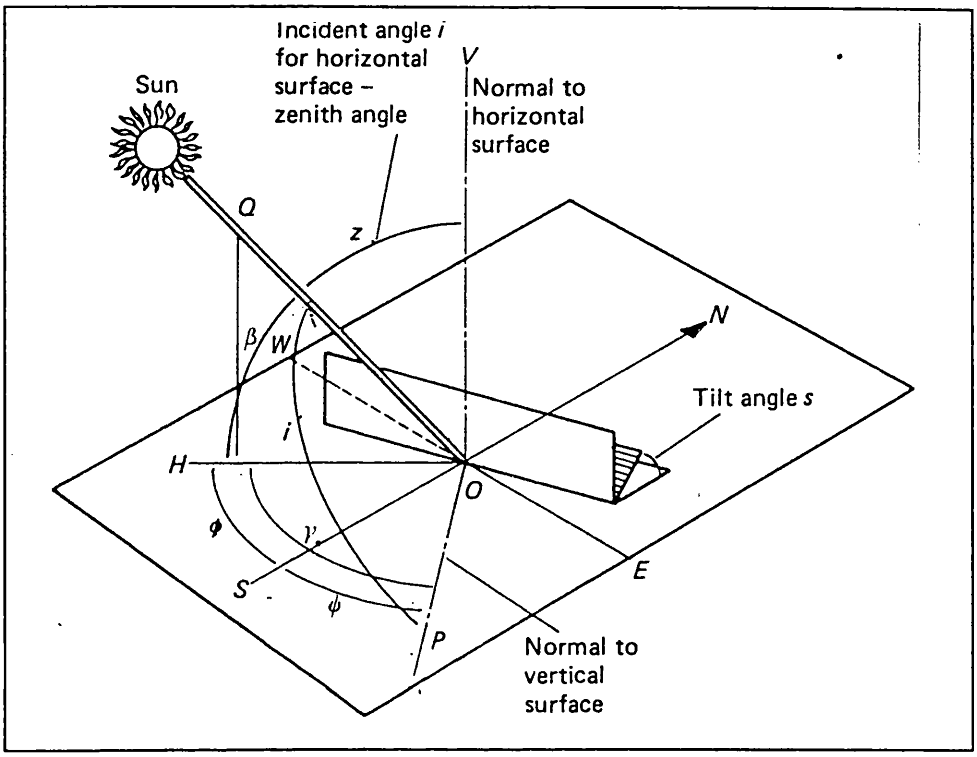


Figure (13: Solar angles for vertical, sloping and horizontal surfaces. (Markus et al, 1980: 172)

Solar altitude $\beta = \angle QOH$; Solar azimuth $\phi = \angle SOH$; Zenith angle $= \angle QOV = 90 - \beta$;

Incident angle $I = \angle QOP$; Wall azimuth $\psi = \angle SOP$; Wall-solar azimuth $\gamma = \angle HOP$.

Using this method, the mean hourly global, diffuse and direct irradiation on both horizontal and vertical surface in Tripoli is estimated for the months of December and June as a sample of summer and winter conditions, Figures(14), (15)

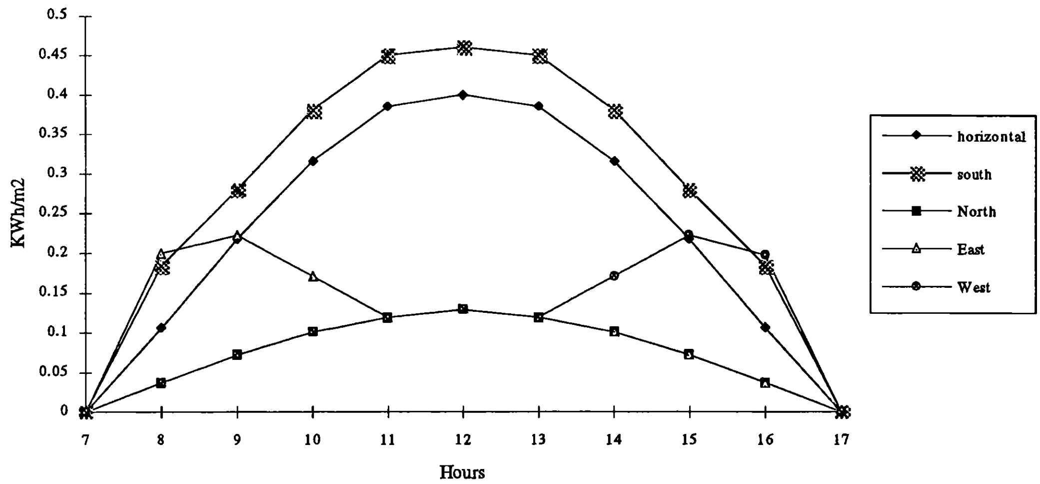


Figure (14): The estimation of the monthly mean daily global irradiation on horizantal and vertical surfaces for Tripoli in December

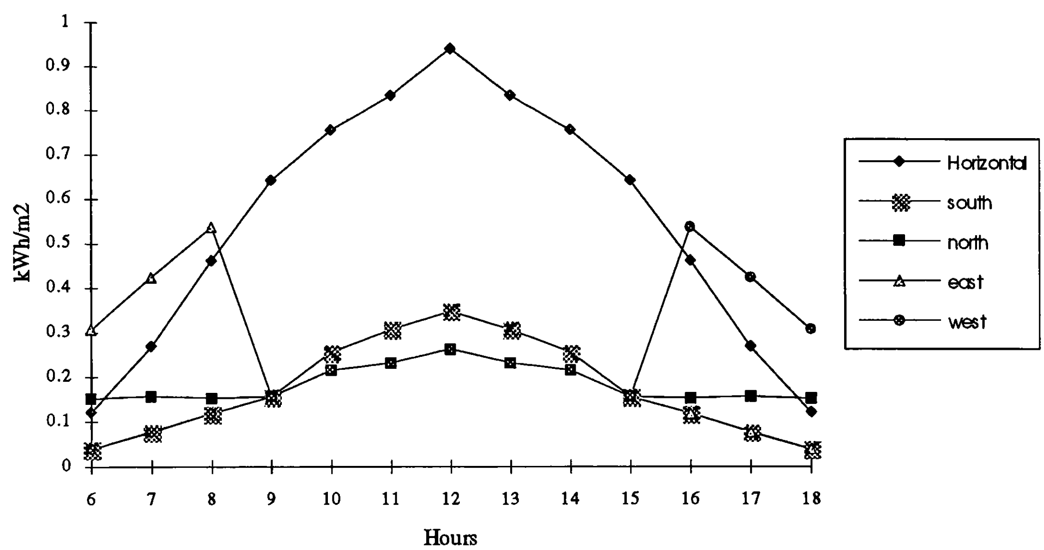


Figure (15): The estimation of the monthly mean daily global irradiation on horizontal and vertical surfaces for Tripoli in June

2.3.2 Temperature:

Temperature can be defined as the thermal state of matter with reference to its tendency to communicate heat to matter in contact with it. With respect to air temperature, it is the rate of heating or cooling on the earth's surface which determines the temperature of the air above, (Goulding, et. al.,1992.p225). The distribution of temperature may vary according to a number of factors,

1- Sun movement and location: By changing the sun's position (as a source of heat) throughout the year and day.

2- State of the sky (cloud and cloudless): The sky also has a role in the variance of temperature, due to its condition as cloudy and cloudless. On a clear day, a large amount of incoming diurnal radiation and a free path for out-going nocturnal radiation produces a wide daily temperature range.

3- Air movement: Temperature may vary also according to the wind which can easily be noticed on a coastal site through the influence of off-shore and on-shore breezes, generated by the daily cycle of land -sea temperature differences.

The following data is required to predict the influence of temperature on the thermal performance of a building:-

1.Monthly mean temperature, (figure 16).

2.Monthly maximum and minimum mean daily temperature, (figure 16).

3.Monthly absolute maximum and minimum temperature over a daily cycle, (Figure17).

Although temperature have been measured in Tripoli since 1879, the data is incomplete. However, this study is based on data collected by the Secretariat of Scientific Research Centre for Solar Energy Studies in Tripoli, Figure (16).

From this data it can be seen that the minimum temperature is founded during the months of January and December, where the temperature ranges from 7° C to 10° C. during the day, and from 4° C to 10° C during the night, and it could in extreme conditions drop below zero. Temperature peaks during June and July with a daytime range between 28° C to 38° C and a range between 23° C to 28° C during the night. Extreme conditions have raised the temperature to 42° C or more in daytime. Figure (17) shows the diurnal temperature of June, and December.

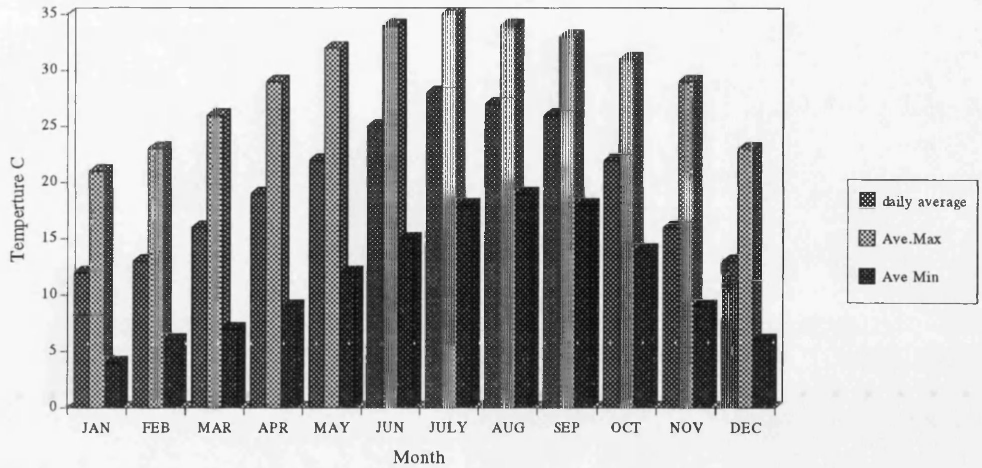


Figure (16): The monthly mean average temperature for Tripoli. Based on data from CSES

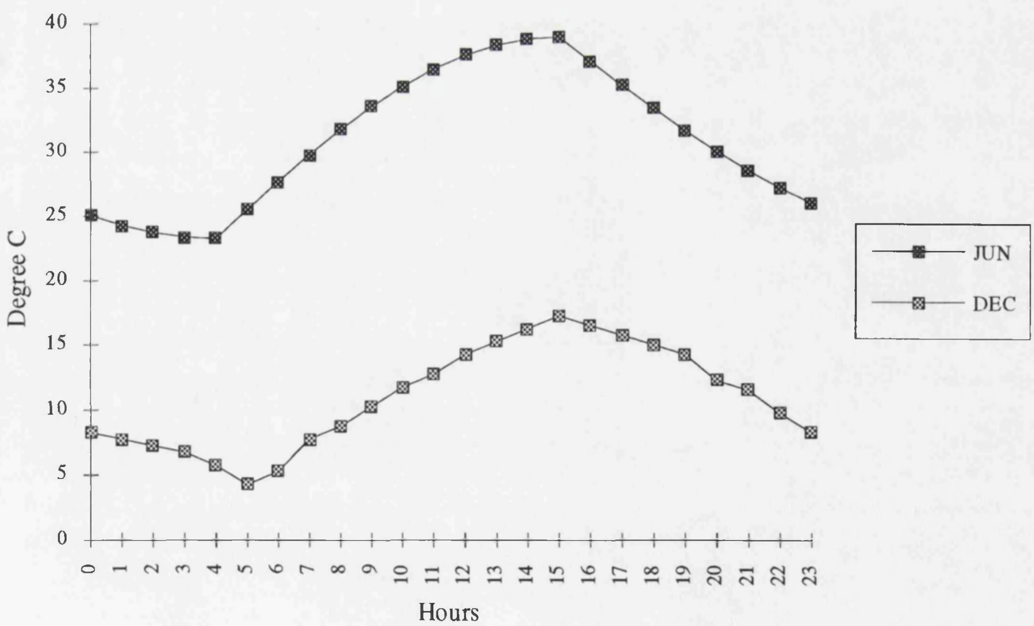


Figure (17): Tripoli's monthly mean daily hourly temperature profile for June and December

For design purposes, solair temperature can be a convenient way to express the sun's influence. It is defined as "the hypothetical temperature", which will give the same temperature distribution and heat flow in a building element that would result from the impact of the actual combination of the absorbed short wave radiation, long wave exchange with sky and ground, and forced convection due to the wind at the given external air temperature. (Goulding et al., 1992: 225). This temperature varies according to orientation and tilt as we find in, figure (18), solair temperature in June rising to 52° C on the horizontal and dropping to the air temperature on a north facing vertical surface.

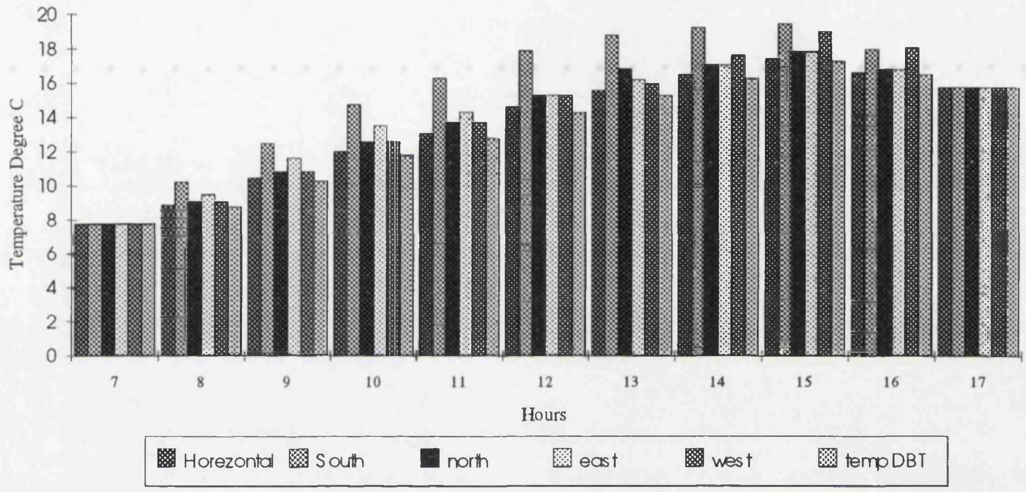


Figure (18):External Temperature and Solair Temperature on white horizontal and vertical surfaces

Another useful hypothetical or conceptual temperature is the "equivalent external air temperature" Teo, which will have the same effect under steady state conditions as the actual temperature under periodic heat flow conditions. This is specific to each different construction (roof, wall, etc), representing the outside temperature as dynamically 'seen' from the outside by expressing its thermal damping and time lag. Mean daily Teo is normally equal to mean daily To.

2.3.3 Humidity

Humidity is the water vapour within a given space, while Relative Humidity, RH, is the ratio of the amount of water vapour in the atmosphere to the maximum amount of water vapour that can be held at a given temperature, (Goulding, et al.,1992: 224). The maximum amount of water in the atmosphere is the saturated vapour pressure in a given temperature. Therefore, at the same temperature, Relative Humidity will be calculated as follow:

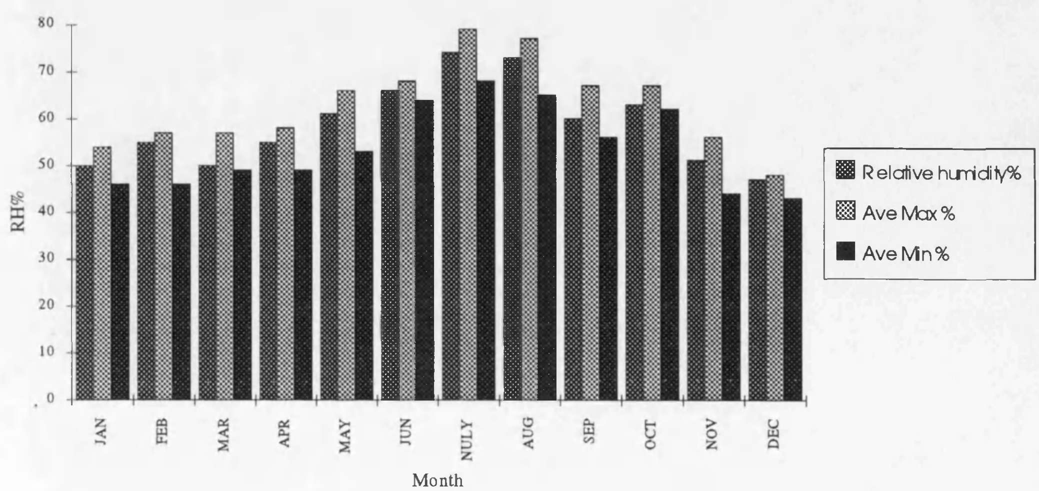
RH= Vapour Pressure / Saturated vapour pressure at the same temperature * 100 %

RH may vary according to a number of factors. It varies according to the altitude and as Evans points out (1980), a 100m increase in altitude will slightly increase the RH due to the drop in temperature. and location. This is variation is due to geographical and topographical location in a macro, meso, and micro senses which is clearly noticed for example in the differences between coastal and inland locations.

This difference tends to be greater in the hot dry zones, where humidity is easily recognised as we get closer to the coast. RH is also varies over a daily and seasonal cycle. In day-time RH reaches its maximum just before dawn and it gets to its minimum by mid-day or early afternoon.

The data required for measuring the influence of RH on thermal performance basically deals with the relationship between temperature and absolute humidity. The latter can be expressed by measurement of vapour pressure or found by measurment of both 'wet bulb' and 'dry bulb' temperature.

This data is assigned to a psychrometric chart, which expresses a mixing ratio of humid to dry air, and/or vapour pressure, as a function of dry bulb temperature. The limit of moisture which can be held in the air is the dew point or saturation curve. The equations for this relationship are attributed to Magnus in 1844. Humidity data is available from the CSES in Tripoli. The maximum and minimum monthly average relative humidity throughout the year, is shown in Figure (19). RH in summer is affected by Tripoli's location and the relatively high temperature , averaging between 66% to 80%, and can rise up to 90% in extreme conditions. In winter the humidity is relatively low, ranging between 43% to 55%, and can drop down to 40%.



Figure(19) Monthly Mean avearage,Min.,Max. Relative Humidity for Tripoli. based on the data available from CSES.

2.3.4 Air Movement:

Boutet indicates (1987: 1), that Wind is a natural form of air movement, which usually flows horizontally. The wind affects a city on three scales, the major wind system, a secondary pattern, and the meso/micro- climatic system .

Fig(20), Air pressures of the secondary circulation system s "Controlling Air Movement", 1987, P. 5.

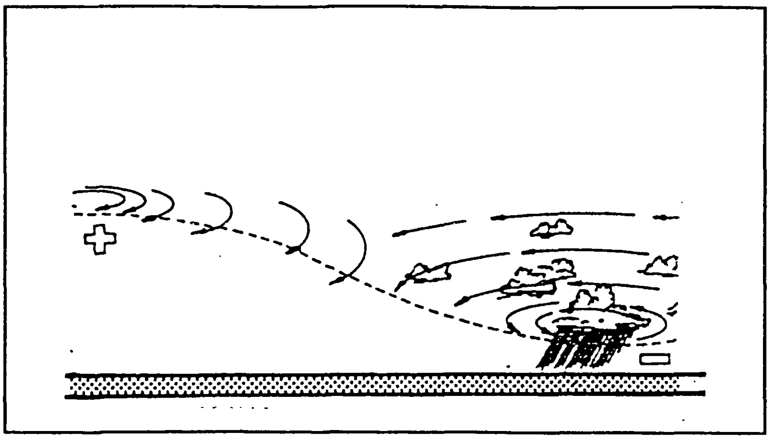


Figure (20), Air pressures of the secondary circulation system's , (Controlling Air Movement, 1987: p.5)

a) The major wind system:

The major wind system "is a result of uneven heating in the atmosphere caused by the differential radiation balance on the earth's surface, which varies with latitude and sun position throughout the year. As the sun heats the surface, the air expands and rises, then is replaced by cool air; the exchange of air creating a cycle known as the general circulation (the major wind system of earth)"(Markus 1978 p167). This general circulation consists of three main global belts, which are curved by the influence of the earth's rotation, and its speed increases with latitude.

b) Secondary pattern:

Within the major pattern, there are several secondary air movement patterns, Figure (20), which have lesser intensities and occur in smaller areas. These are usually influenced by pressure, as the air moves from positive to negative zones.

c) The meso/micro- climatic system:

The meso/micro scale winds which are founded from the effect of terrain and site location, also differ due to characterstics, e.g. NewYork will generate differences compared with a low-rise renaissance city such as Prague. The pressure (the impact of air caused by variation of force and air density) causes the horizontal air movement, and buoyancy (the vertical movement of the air due to the different in temperature) causes vertical movement. These then are the interactive forces that control this type of wind.

The determination of the wind effect is based on the availability of certain data such as:

a) Wind speed and direction.

b) The modification of the operative wind pattern by local topography.

c) The comfort evaluation (desired breeze / unwanted winds)

Tripoli's air movement

During the summer months in Tripoli there are two type of desirable cool breeze one from the N-NE with a speed range from 2m/s to 3m/s, and the other from the NE-E with a speed between 1 m/s to 4m/s, which are present for almost 50% of the year. The lack of barriers around the city also causes it to be influenced by undesirable hot and sandy winds (Gibli) from the desert, having a direction of S-SE and speed range from 2m/s to 7m/s. This wind is present for a few weeks in July and August. Winter brings undesirable cool winds from the NW-W with a speed range from 3m/s to 3.5 m/s, Figure (21).The most frequent wind direction is from the north and west with a speed range from 3m/s to 6m/s.

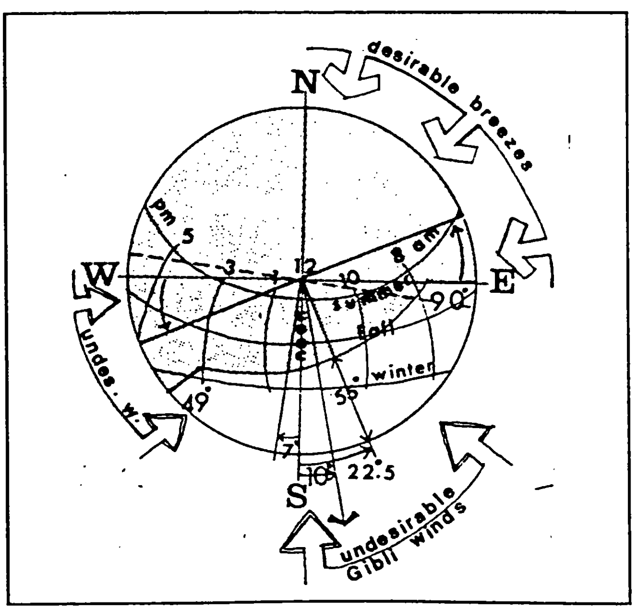


Figure (21): Winds: desirable and undesirable , Tripoli.

2.3.5 Precipitation

Precipitation "occurs when the temperature of the saturated air mass drops to a critical point, and creates condensation in cloud form. In the warmer zone where the air expands the cloud releases its moisture as conventional precipitation". (Goulding, 1992)

The climate in Tripoli is characterised by a dry summer, and a rainy winter, and the highest level of precipitation is generally in the western region. The mean annual precipitation ranges between 250 mm to 400 mm, and the maximum range of rainfall is experienced during December and January when 50mm to 100mm fall each month, Figure (22)

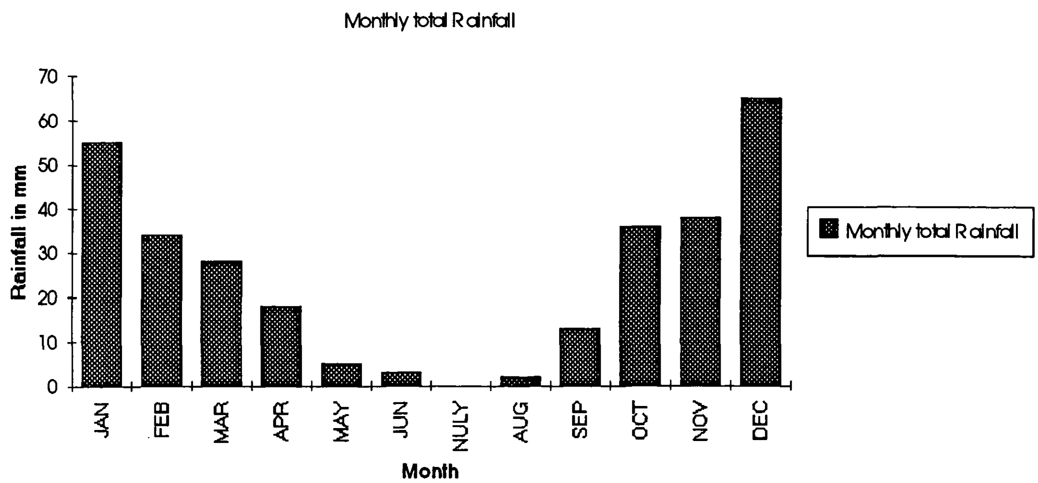


Figure (22): Tripoli, Monthly Average total Rain fall, (based on Libya Atlas data).

2.4 MICRO-CLIMATE: (Tripoli)

The micro climate as a category deals with the influence individual or small groups of buildings and their surrounding landscape have on thermal performance.

2.4.1 Building surrounding:

The environmental influences on and of a building or a group of buildings in its immediate artificial spatial context are principally those of solar radiation and air movement.

1- Solar radiation.

The influence of the structural surroundings on solar radiation can be seen in two ways: reflection and shading,

a) Reflection is essentially controlled by three aspects: the distance between walls and their dimensions, the angle of the sun (sun movement pattern through time), Figure(23), and the material of the building's surface, a critical factor in terms of its reflectivity and obsorbtivity.

b) Shading is mainly determined by the three fixed dimensions of a building and movable shading devices associated with a user-determined time schedule. Shading obstructions are needed in certain climates such as the hot dry climate where protection from sun is a prerequisite. However during winter fixed shading may be considered a negative aspect, since it causes overshadowing when solar radiation may be usefully captured to displace a space heating load.

Figure (23): The Air movement pattern according to the lay out

2-. Air movement.

The geometry of a building or group of buildings in its context can influence the air movement pattern and velocity. This must be analysed carefully, as a building at right angles to the air flow may decrease the velocity of air up to 60%, while buildings laid out in a row parallel to air flow develop pockets of turbulence which contain little through air movement. One the other hand if the layout is positioned in an alternative pattern, the flow of the air may be deflected off each succeeding building as the air travels down-stream, and each building receives air movement. Figure(23)

The particular urban fabric of Tripoli can be divided in two main components, the old city and the modern part.

a-In the old part of Tripoli the urban fabric is compact, as buildings share two or three walls with other building. Thus the exposed surface is minimised, as well as the narrow streets providing shading almost all of the day for much of the vertical building surfaces. Protection from the sandy wind in summer is an added bonus..

b-In the modern part, which lies opposite the old city, the layout has been affected by the introduction of mobility and the change in human requirement for bigger gardens with the influence of the western style of living. Therefore, the streets have become wider and detached buildings have become more popular. The climatic changes due to this new distribution have been neglected, although the spacing between the buildings is controlled by the building laws for each part of the modern city.

2.4.2 Vegetation.

Vegetation can also strongly influence the micro-climate of a site through its ability to modify not only solar radiation but also humidity and temperature.

a) Solar radiation can be intercepted by vegetation as shading elements. This provides screening and filtering which can be managed by type of planting - evergreen / deciduous, form, height, etc. The horizontal surroundings covered by planting or grass will reduce the amount of reflected radiation as well as cooling by evaporation, and hence tend to mitigate extreme temperature. In addition this should also help to cool the soil as the cover of vegetation absorbs the initial thermal shock. The thermal properties of the sub soil are relevant in this respect.

b) Vegetation may also influence air movement by acting as a barrier to the unwanted winds and directing the wanted one towards the building. Figure (24) shows the effect of the trees size and position in modifying air movement pattern; i.e, by creating low and high pressure zones to orient the wind away or toward the building. Conifers offer year-around protection. Deciduous trees afford more shelter when they are in leaf in summer than when they are bare in winter.

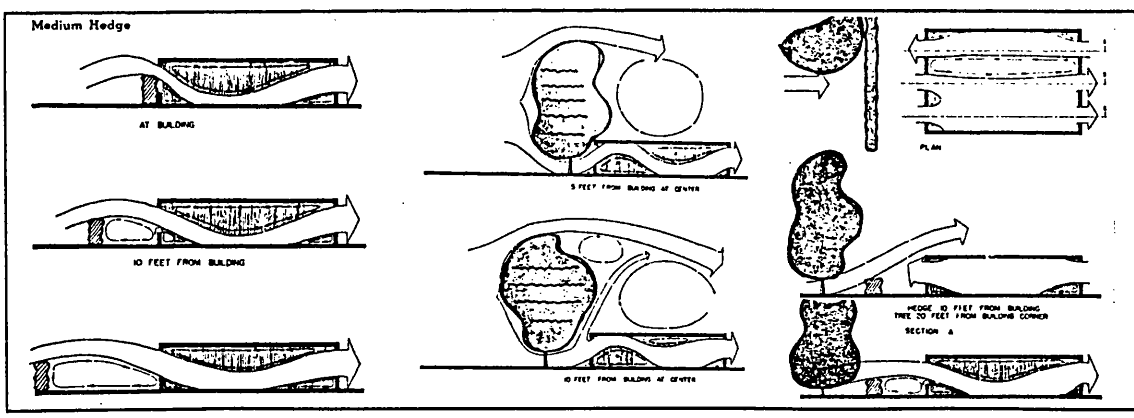


Figure (24): The Air movement Pattern modification with the landscaping. (Olgyay,et al. 1975: 102)

c) Vegetation as an efficient modifying element, and strategic decisions with respect to the type, size and distance intervening, may rely on design aids such as wind tunnels, and computer methods.

The use of Vegetation in Tripoli.

Most of Mediterranean vegetation grows in the city where the soil (fertile and consisting of a high amount of organic materials, and clay) encourages growth. This in turn encourages Libyans to use vegetation to modify their climate. For example vines grow easily and are one of the most popular shading devices in the city.

The greatest intensity of solar radiation occurs on roofs and east and west facades. The east facade is not such an acute problem as the west as the ambient temperature is lower in the morning. Therefore, it is preferable to exploit this to protect roofs and west walls - growing secondary roofs and walls in the form of pergolas and screens which are economic, look good and perform a valuable environmental function.

In order to modify the sandy wind from the desert in summer, deciduous trees should be grown so as to protect the south facade in summer while allowing solar radiation to penetrate in winter.

2.4.3 Topography;

This element has a major effect on the micro-climate and in turn on the thermal performance of a building. This effect can be explored through the following categories:

1) Solar radiation:

A slope or hillside may receive up to 20% more radiation than a level surface, (Olgay, 1967). This varies with the inclination and the direction(azimuth) of the slope.

2)Air temperature:

A rise of the terrain affects the distribution of temperature. As cool air is heavier than the warm air, it flows towards the lowest point, and consequently creates a cold island; and with outgoing radiation at night, a cold air layer will be developed near the ground surface. (In temperate areas this becomes a "frost hollow" in winter).

3) Air movement and precipitation: The effect of topography on the distribution of wind and precipitation develops when wind flow is directed over a hill, causing a higher speed on top of the hill, and also creating a lower speed at the opposite side of the hill (shadow). The precipitation is influenced by the wind when it is carried by air movement over the hill, strikes the slope and falls on the other side.

Tripoli's Topography.

Tripoli's terrain is almost flat, although there is a gradual slope from the sea towards the mountains. These rise up to 200 m to the south Jefarra plain, which extends for

100km in width south of the city. The distance from the city and the height of the mountain renders its influence negligible.

The city experiences off-shore and on shore winds as a result of its location on the coastal front of the Mediterranean Sea. This has a major influence on its micro-climate. Naturally this influences the sea-front area more than the south part of the city since the temperature rises gradually from the sea front towards the south. Therefore most of the city roads are laid perpendicular to the sea to allow the flow of sea breezes thoughout the city.

Strategic summary.

A knowledge of the regional and local climate is an essential input which will form the basis of analysis to characterise year-round performance. Once the 'positive' and 'negative' climatic influences have been identified, these can be modified to improve the microclimate of the site around the building; which in turn, if replicated enough, could provide significant benefits to the general meso-climate of the region.

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3.0 HUMAN SYSTEM

3.0 THE HUMAN SYSTEM:

The human system, as a component of the study, is explored within the context of both physical and psychological aspects. Their influence on thermal comfort is examined in relation to other systems of the environment and building, concluding by reviewing the systematic procedures that have been developed in this field for adapting the design of the building to human requirements and climatic conditions.

3.1. PHYSICAL ASPECTS:

The thermoregulatory sub-system, is a complex of autonomic and voluntary responses that govern the rate of heat loss from the body and in some cases, it's heat production as well (Givoni, 1976: 30). This is affected by :

1) Environmental Parameters.

2) Individual Parameters.

3.1.1. Environmental Parameters:

The effect of the environmental factor on the Physiological and sensory responses can be illustrated in the following four parameters:

1) Room temperature
2) Air movement (air velocity).
3) Relative humidity.
4) Mean Radiant Temperature (MRT).

1) Room Temperature

Without the influence of other environmental factors (radiation, air movement and RH), the temperature is an important factor in thermal comfort, as 2/5 of the heat loss from the body is by convection within the room. Thus, in order to maintain the temperature in the thermal comfort zone, it must normally be between 16°C to 28°C for daytime and lower for sleeping rooms. However, if the temperature is above or below this level, thermal comfort can be achieved by increasing / decreasing the level of activity or the thermal resistance of clothing, or the level of the air movement.

2) Air Movement (air velocity):

Air movement affects heat loss from the body through convection. The association air movement, and air temperature is important. For example in a hot climate, an increase in air movement will increase the amount of heat loss from the body, as well as increasing the evaporative cooling from the skin. This could provide thermal comfort. It is indicated by Goulding (1992: 113) that within buildings the air speed is generally less than 0.2 m/s, and the range of air velocity relative to level of activities between 0.1m/s and 0.2 m/s for indoor sport.

3) Relative Humidity:

The relative humidity comfort value ranges between 20% to 80%. So, if it is below 20% a distinct discomfort will be experienced because of the dryness, or if it is above 80% it will create a feeling of damp (ideally the level should not drop below 40%and not exceed 70%). It is known that human tolerance toward humidity is much greater than temperature, but at the high level of RH comfort starts to be rapidly affected. At such high levels it is necessary to decrease temperature in order to maintain comfort. For instance, the increase of the relative humidity from 20% to 60% will need a decrease in the temperature of 1°K. (Markus, et. al, 1980).

4) Mean Radiant Temperature (MRT):

MRT is the temperature of a uniform black enclosure in which a solid body or inhabitant will exchange the same amount or radiant heat as in the existing non-uniform environment, (Goulding, et. al. 1992: 225). MRT influences heat loss in two ways: One, is conduction (when the occupant makes contact with the surface). Second, is by radiant heat loss. Therefore, discomfort will be experienced when the MRT is above or below the air temperature by a few degrees (nearly 5°C). In addition an MRT value of 2-3 K above air temperature can enhance comfort.

Another cause of discomfort is when the temperatures are equal but with the effect of intense incoming solar radiation and its effect on the opposite surface causing a high level of outgoing radiation. By using a suitable insulation for the external walls of the room will reduce the MRT to be close to the room temperature.

3.1.2 Individual Parameters:

1) Metabolic Energy:

In order to be in the comfort zone the metabolic energy of the body should be balanced with the environment; i.e. the heat loss from the body by sensible (energy exchange during change of temperature) and latent (energy exchange during change of state), through skin diffusion, evaporation, sweat secretion, latent respiration, dry respiration, radiation and convection should be equal to the metabolic energy. The body heat balance can be illustrated in the following equation:

	Metabolic +/-	**Stored**	**= Evaporation +/-**	**Radiation -/+**	**Convection +/-**	**Conduction**
Typical (%)	80%	20%	=	25%(a)	45%(b)	30% (c)

(a)will rise in hot weather, (b)will increase with cold weather, (c)will rise in wet/windy weather.

The level of the metabolic energy depends on the level of activity, ranging between 204 W/m^2 for heavy machine work to 41 W/m^2 for a sleeping person. The standard unit of activity level is the MET which is equal to 58 W/m^2 (The typical output for an awake but non-active person).

2) Clothing:

Clothing is a thermal resistance layer that controls the level of heat lose from the body to the surrounding atmosphere, (Evans, 1980: 21). In summer traditional clothes of a hot climate have a low value of thermal resistance of nearly 0.5 clo (clo is the unit of thermal resistance due to clothes and is equal to 0.155 m^{2}K/W) while in a cold climate in winter, clothes are thick with thermal resistance of 1clo or more. However, individual perception of thermal comfort is partly psychological and this must be considered in association with physical parameters.
These physical parameters vary from one person to another, and by the age and sex of the individual.

3.2 PSYCHOLOGICAL ASPECTS:

3.2.1 Behavioural response and adaptation:

Markus (1980), refers to human behaviour and gives indicators in this respect relative to comfort zones. This data is based on actual adjustment to personal behaviour that takes place in an occupied space. These adjustments are to clothing and muscular effort, i.e. a human response to changes in the environment, as well as to the surroundings such as open and closed windows, the use of curtains and blinds, and the moving of personal work place. These responses may differ from one person to another and from one nation to another.

In each country people have developed their own techniques for adapting to the climate which may not work with the others. For instance, concerning social response in Libya, Libyans have adapted themselves to the climate by wearing traditional white clothes. In addition there is a seasonal migration which is a traditional technique used by Libyans. This migration occurs during late June until the end of August, as they move from the hot areas in the cities to the cooler areas in the country, while in the low lying areas the population moves in summer to the high lands. These actions are related to both a cultural factor and acclimatisation.

3.2.2 Acclimatisation:

Acclimatisation is the result of regular exposure of the human body to the same climatic conditions. Thermal comfort level changes according to the season. The degree of acceptable comfort for humans in the external environment for summer is higher than winter.

Specific user requirements of 18°C - 22°C are unnecessarily rigid (Fordham, 1981: 232). As a general rule, people have been encouraged in their cultural environment to originate pragmatic building design as well as clothing that adapts to situations which are appropriate to the outside thermal environment.

Culture and religion may also have an impact in determining thermal comfort. It has significant control over the type of clothing as well as the building design. Habib argues (1975), that Libyans didn't abandon their spiritual values in order to acquire the tools of modern society. Therefore, privacy is an issue in the building design which should be studied carefully, so that it will not compromise thermal performance.

3.3 COMFORT CHARTS:

The combination of the physical parameters that control the balance of thermal comfort into one single parameter, has been the objective of many studies. Some attempts are based on subjective thermal sensation, while others are related to physiological responses. These thermal indices are readily accessible ways of presenting the relationship between thermal comfort parameters and physical parameters.

Standard Effective Temperature (SET).

One of these indices is the Standard Effective Temperature (SET), which is further develop of the effective temperature. This defined as the uniform temperature of an imaginary enclosure at 50% relative humidity in which human will exchange the same total heat by radiation, convection and evaporation at the same mean skin temperature and skin wetness which occur in the actual environment. (Markus, et. al. 1980: 48).

The SET suggests that uniform environment is standardised at 50% RH, air velocity at 0.125 m/s (still air conditions in a room), activity of 1 Met and intrinsic clothing at 0.6clo.

Determining the thermal comfort using SET:

First, find the operative temperature from the chart illustrated in Figure(25), with the level of the activity, air temperature, MRT, and air velocity known. Second, with a known relative humidity and by taking the activity level, clothing and air velocity, in chart, Figure(26), the SET, DISC (degree of discomfort), and the skin wetness can be determined.

The measurement of the discomfort level will be based on the utilisation of thermal sensation scale, the Predicted Mean Vote (PMV), superimposed on the psychrometric chart (Figure27). This is the mean of a large group of individuals expressing a vote on their thermal feeling under different thermal circumstances, and has been used to provide an index for thermal comfort, Figure (27).

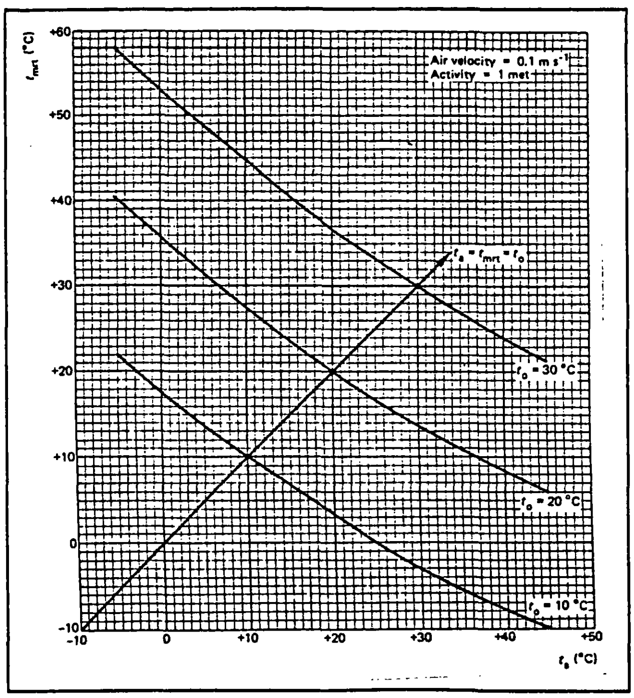

Figure (25): Operative Temperature Chart, After Fanger (Markus, et. al., 1980)

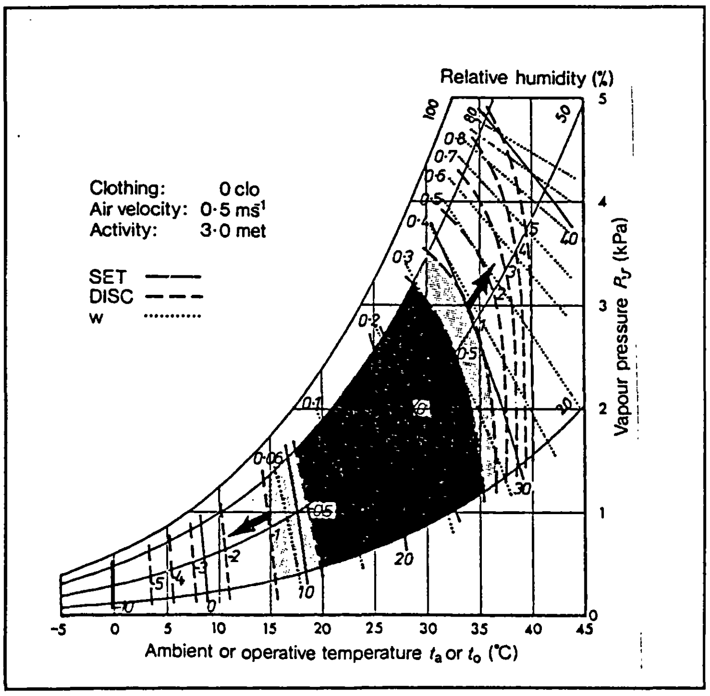

Figure (26): Thermal Comfort Chart

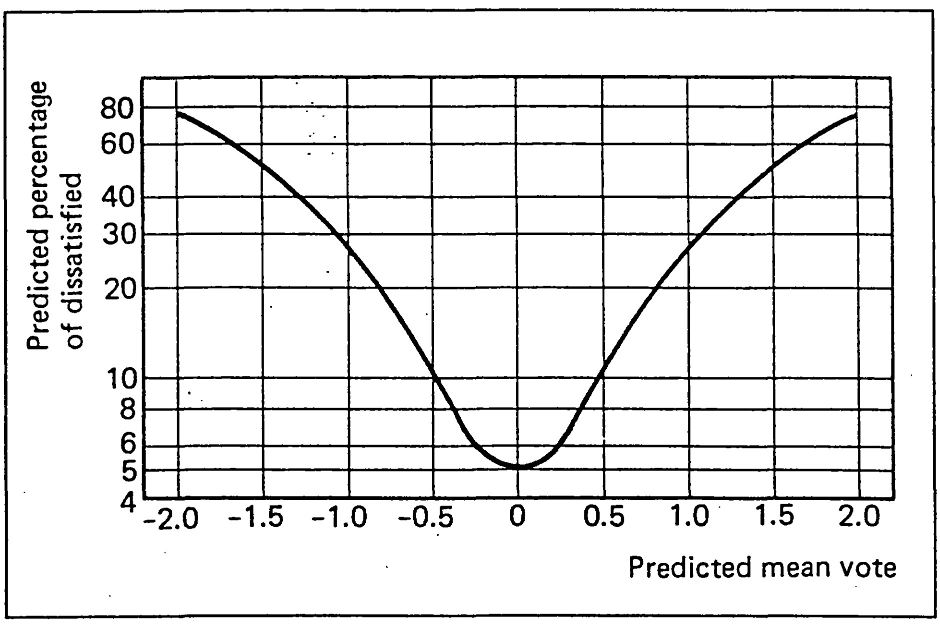

Figure (27): Predicted percentage of dissatisfied as a function of predicted mean vote. After Fangner (Markus, et al. 1980)

3.3.1 Bioclimatic Chart by Olgyay.

The Bioclimatic chart developed by Olgyay, was the first proposal of a systematic procedure for adapting the design of a building to human requirements and climatic conditions, (Konya, 1980: 28). The chart expresses the comfort zone by plotting temperature as a function of RH, and overlapping with a series of scales for environmental variation, which can then extend the comfort zone beyond its normal boundaries. For example, extra radiation can provide comfort at low temperature virtually irrespective of RH; air movement can extend comfort at high values of RH; and more moisture can extend comfort at low values of RH.

Summer and winter comfort zones are given independently, Figure (28). The greater tolerance of warmth in summer is relative to a lower expectation of the need for warmth in winter. In reality this is an outdoor, rather than indoor, phenomenon. Indoor aspirations, particularly in a work situation, tend to cooler temperatures in summer than winter.

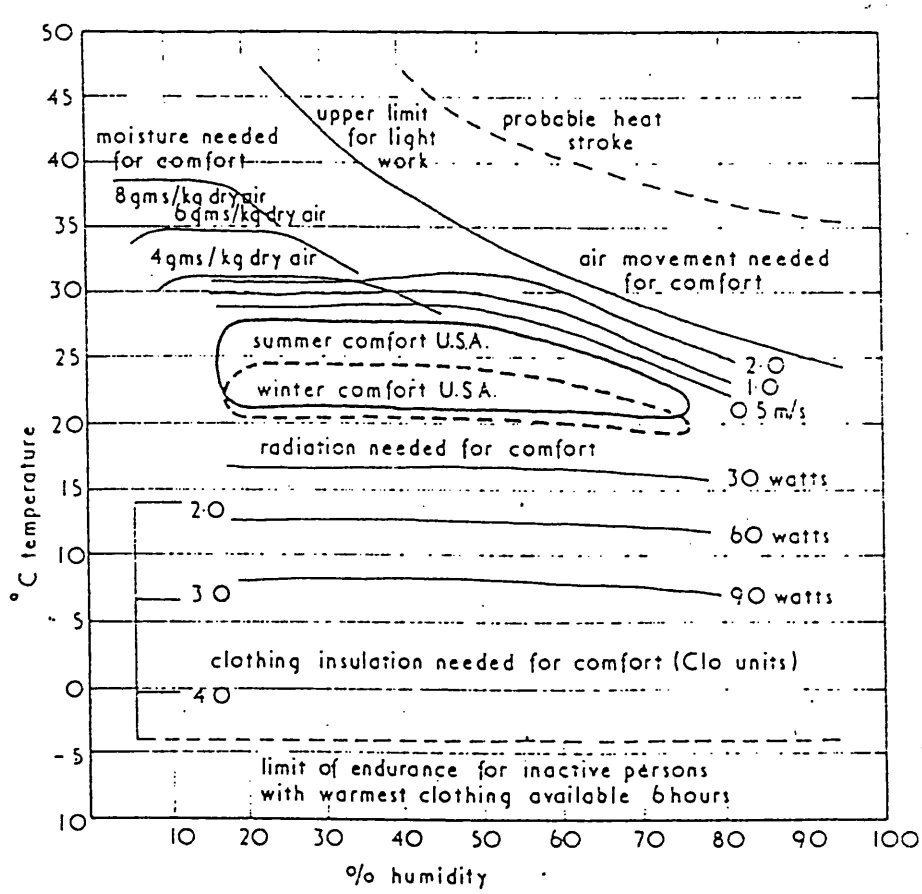

Figure (28): Olgyay's Bioclimatic chart

Indeed, Givoni points out, (1976: 310), that since the chart is based on outdoor conditions that it is not widely applicable to conditions within buildings. However, this appear to be a debatable point, with at least the principles lying behind Olgyay's chart applicable to buildings. However, it is arguable that it is not suitable for applications where outdoor conditions vary widely with the indoor condition.

3.3.2 Building bioclimatic chart, by Givoni.

Givoni has proposed the building bioclimatic chart, Figure (28) as an alternative method which uses an index of the thermal stress to evaluate human requirements for comfort and from which the necessary features of building design are determined. This also involves an estimation of the indoor climate expected under the given ambient condition.

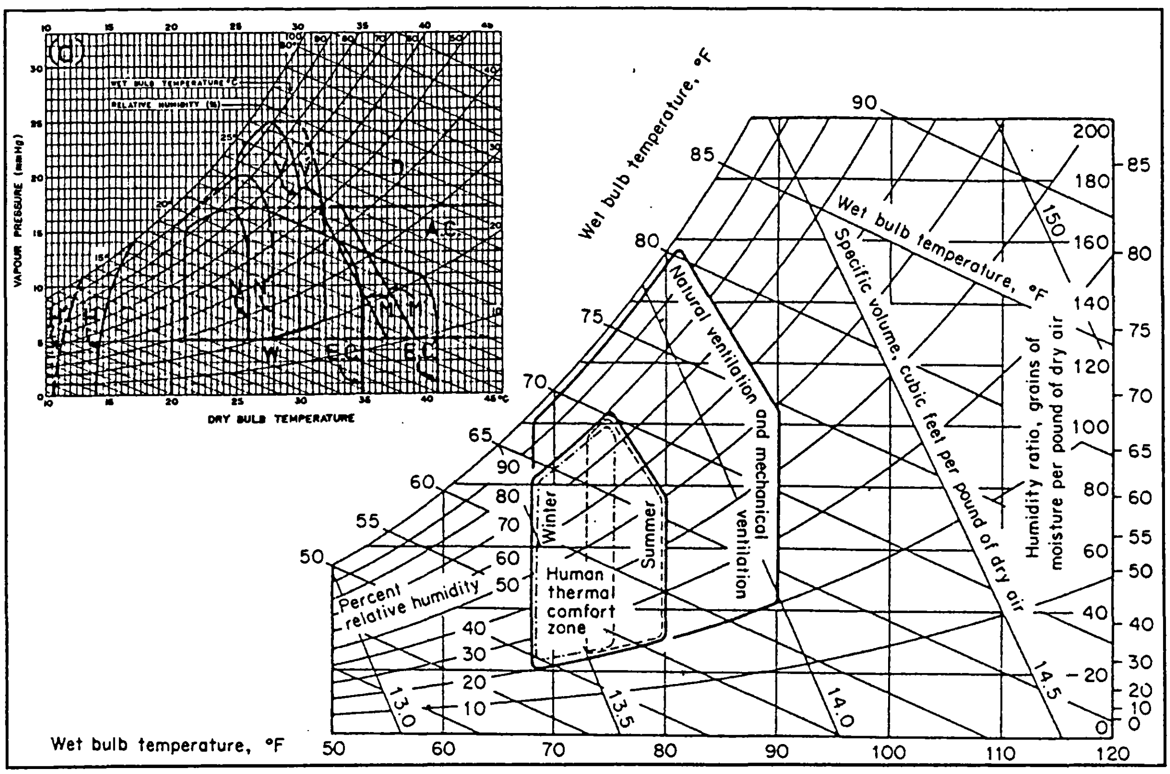

Figure (29) Building Bioclimatic Chart

The Building Bioclimatic chart is based on the relationship between two climatic variables: the vapour pressure and the temperature amplitude.

The comfort zone in the building bioclimatic chart is shown as N, which is the comfort condition for acclimatised people at rest or engaged in sedentary activity and could be extended to N'.

V is the range of comfort which could be achieved using ventilation, but not specifically by minimised heating. This zone is extended to V' in the chart for medium to high thermal resistance with a white external surface.

The range of conditions under which comfort is achievable by control of indoor temperature alone, in the absence ventilation, is marked as M; while the M' zone is the range of achievable acceptable conditions, where the temperature is inversely related to vapour pressure. VM is an overlap area which requires both ventilation and temperature control.

EC denotes where comfort is achievable by ventilation and evaporative cooling for standard building and EC' for well insulated white buildings.

AC is the region where comfort could be achievable by mechanical cooling. Beyond all the above mentioned zones, mechanical cooling must be used to achieve comfort. Dehumidification is required in this region above 17mmHg (0.015 moisture content kg/kg Dry Air) and evaporative cooling is required under (0.004 moisture content kg/kg Dry Air)

H H' limits the zone where indoor temperature is higher than outdoor temperature, making heating unnecessary outside this limit.

3.3.3 Bioclimatic Chart and Design Strategies: case study in Tripoli, Libya

As there is no specific study available for comfort requirement in Tripoli, in this work the determination of human comfort (for Tripoli) is based on the climatic data available from the CSES. The study also includes two types of evaluation of human comfort - Olgay's Bioclimatic Chart and Givoni's Building Bioclimatic Chart.

Olgyay's Bioclimatic chart:

By plotting the data for Tripoli on the chart, Figure(30) it is evident that the need for cooling is more than that for heating. Also the diurnal temperatures have a marked high slope, indicating a large daily range of temperatures. but quite low range of RH. This lies within the possible comfort zone throughout the year, but since the temperature zone gets narrow as RH rises, it becomes increasing difficult to modify the combined effect in summer. Possible courses of action are summarised in the following table (2):

Months, climatic data	Night-time strategy	Daytime strategy
Dec. and Jan. 4<T<18 42%<RH>60%	Maximum heating required ranges between 73W to over 88 W, achievable by high thermal mass, insulated diurnally.	Lies just beyond the comfort zone heating required nearly 50 W,. achievable by high thermal mass with adequate insulation.
Feb., Mar. and Oct. Nov. 8<T>25 45%<RH>63%	Required heating ranges between 73W to58W achievable by thermal mass, insulated diurnally.	Lies in the comfort zone.
Jun. July and Aug. 23<T>39 65%<RH>80%	Natural ventilation, air speed is required is less than 1.02/s as well as dehumidification.	Air speed required over 3.5m/s. Therefore is implied need for active /passive cooling as well as dehumidification
Apr. May and Sept. 15<T>28 49%<RH>60	Partial required heating ranges between 50W to 29W achievable by insulated thermal mass, partly in comfort zone.	Natural ventilation; air speed required less than 1.02/sec as well as some dehumidification.

Table (2):Summary for the cooling and heating strategies according to Bioclimatic chart

Givoni's Building bioclimatic chart:

By plotting Tripoli's climate data on the building Bioclimatic chart, Figure (31: a, b, c, d), the results are summarised in the table (3)

Months	Night-time strategy	Daytime strategy
Dec. and Jan.	lies beyond H' region, heating is required.	lies in H where comfort is achievable by the building envelope.
Oct., Nov., Feb., and Mar..	lies beyond H' region, heating is required.	Lies in comfort zone.
Jun., July, and Aug.	In the comfort zone	Comfort is achievable only by mechanical cooling , with dehumidification
Apr. May and Sept.	Natural Ventilation is required,	Lies in H zone where comfort is achievable by thermal mass.

Table (3): Summary for the Design, cooling and heating strategies according to Building Bioclimatic chart

Both charts indicate a dominant need for summer cooling for comfort. The objective here is to explore passive means of meating this cooling load, with basic mechanical aids provided only as backup during the day time in the extreme conditions of June, July, and August.
It is also the intention to displace the winter space heating load by means of direct passive solar gain; again with auxiliary heating only initiated as a back-up to deal with extreme circumstances.

The temperature and relative humidity (RH) is above the comfort zone. Temperature ranges from 18°C. to 36°C., the RH ranges from 65% to 80%. As the temperature drops, the relative humidity could lie in the comfort zone. However, natural ventilation for cooling in night-time could also be required in these months.

The chart indicates that a cool breeze which is required for these months is more than 3.5m/sec, and the yearly desirable wind in summer ranges from 1 to 2 m /sec which means an increase in the wind speed to about 1.5m/sec is required. These months also fall within high thermal mass structure as the heavy material structure will delay the effect of the peak heating period of the day to the cooler period.

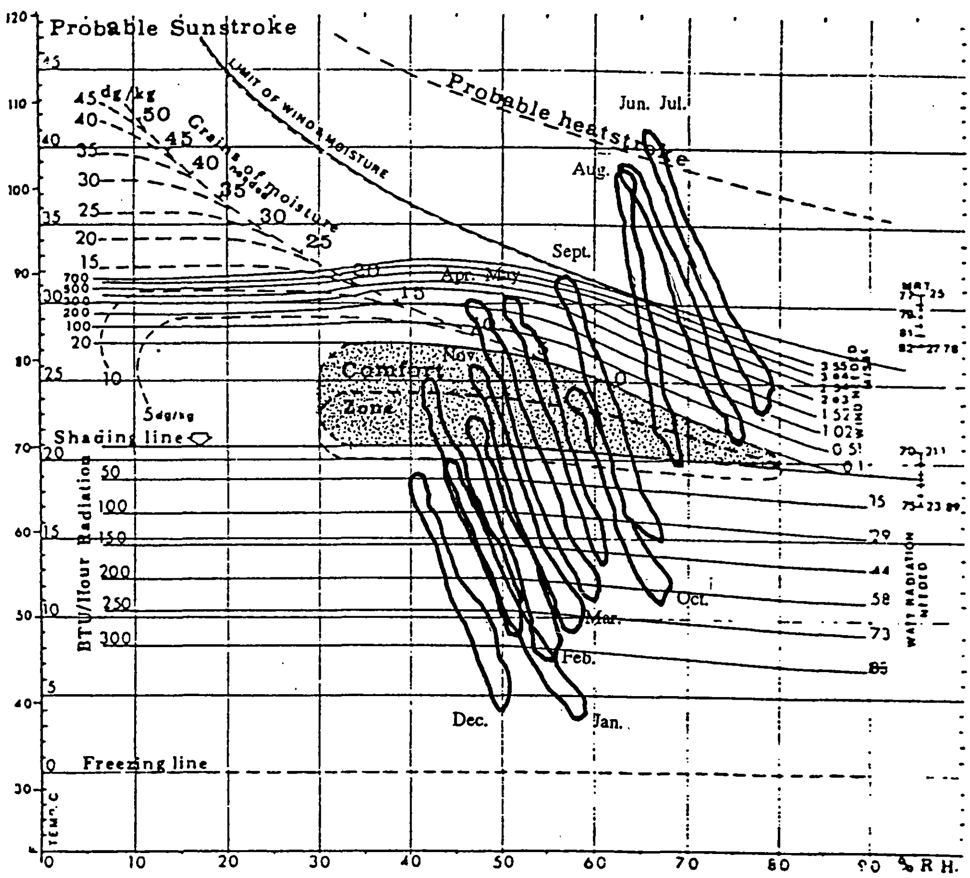

Figure (20): Tripoli's Bioclimatic chart

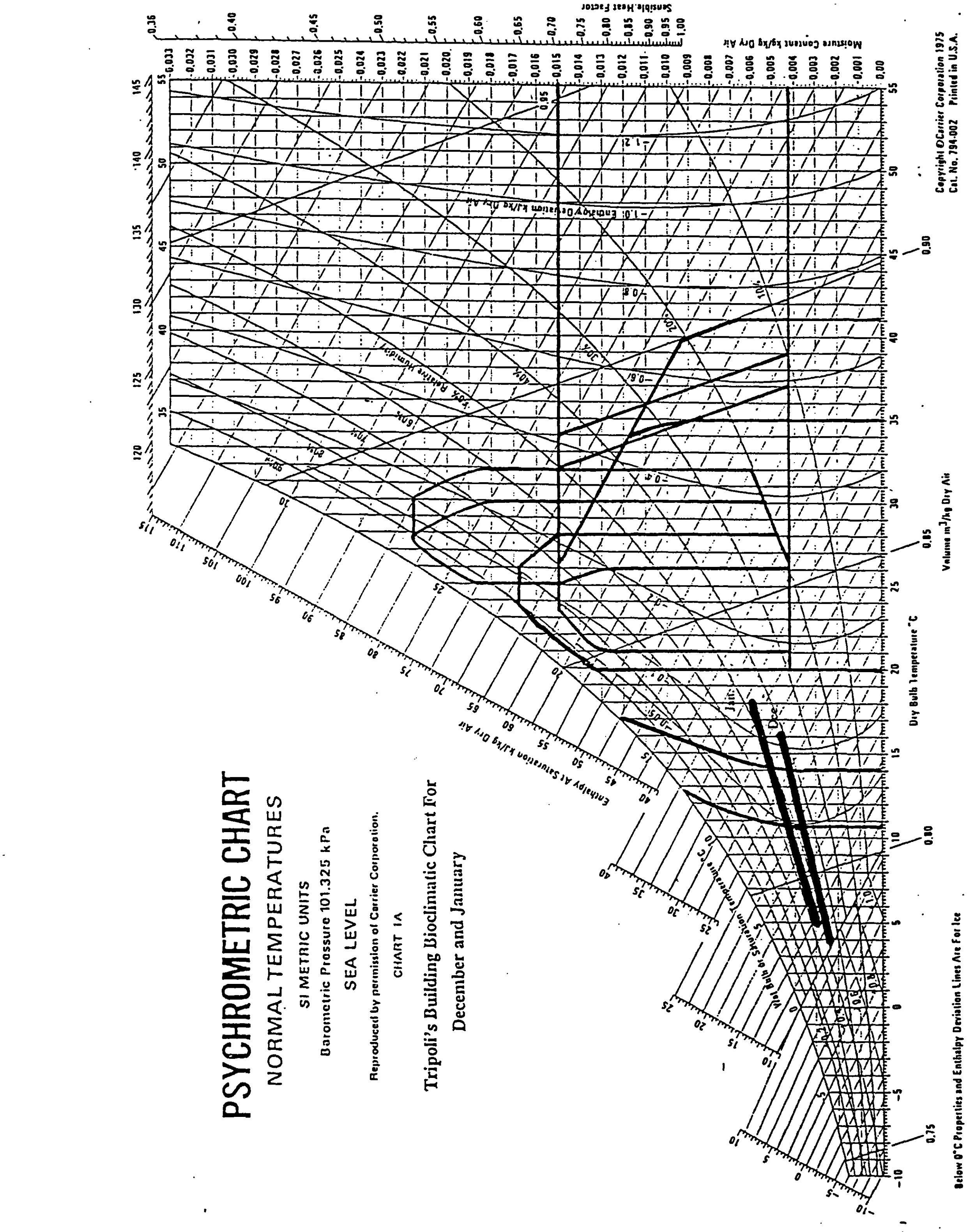
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Reproduced by permission of Carrier Corporation.
CHART 1A
Tripoli's Building Bioclimatic Chart For December and January
Dry Bulb Temperature °C
Volume m³/kg Dry Air
Moisture Content kg/kg Dry Air
Sensible Heat Factor
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Relative Humidity
Enthalpy Deviation kJ/kg Dry Air
Jan.
Dec.
Copyright ©Carrier Corporation 1975
Cat. No. 794-002 Printed in U.S.A.
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice

Figure (31a)

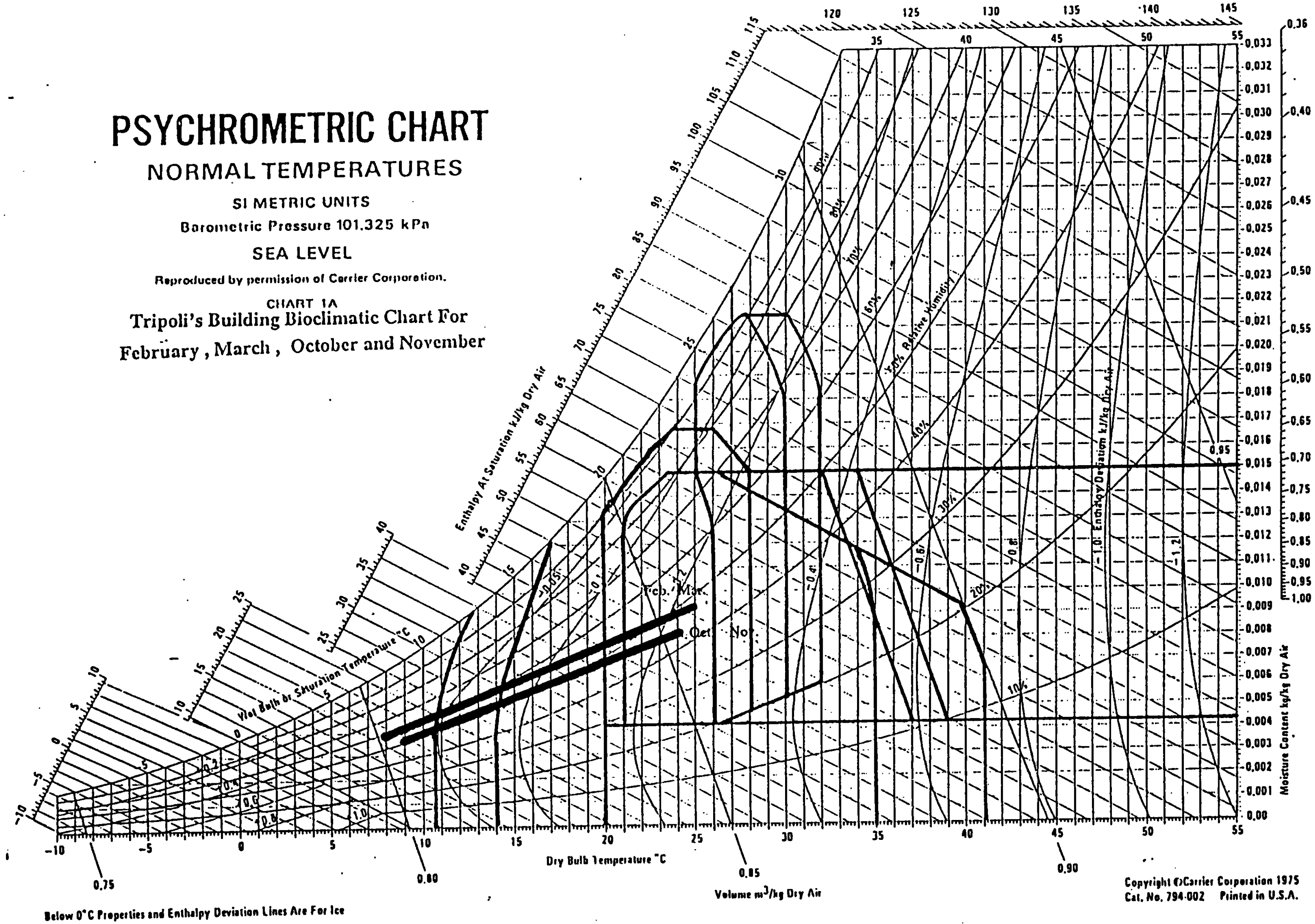
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Reproduced by permission of Carrier Corporation.
CHART 1A
Tripoli's Building Bioclimatic Chart For
February , March , October and November
Feb. Mar.
Oct. Nov.
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Dry Bulb Temperature °C
Volume m3/kg Dry Air
Moisture Content kg/kg Dry Air
Sensible Heat Factor
Enthalpy Deviation kJ/kg Dry Air
Relative Humidity
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
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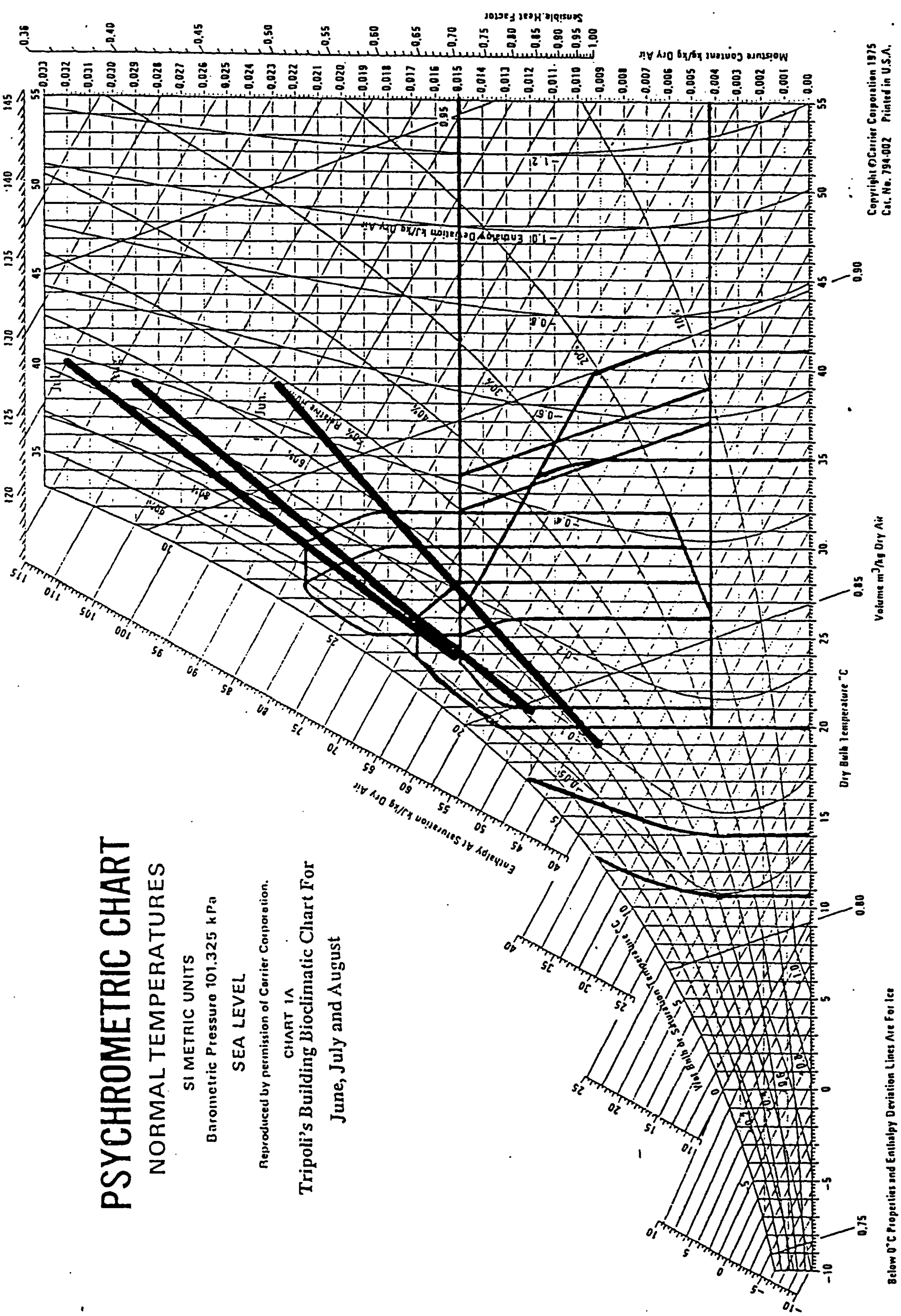
Figure (31b)



PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Reproduced by permission of Carrier Corporation.
CHART 1A
Tripoli's Building Bioclimatic Chart For June, July and August
Enthalpy At Saturation kJ/kg Dry Air
Dry Bulb Temperature °C
Volume m³/kg Dry Air
Moisture Content kg/kg Dry Air
Sensible Heat Factor
Copyright ©Carrier Corporation 1975
Cat. No. 794-002 Printed in U.S.A.
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice

Figure (31c)

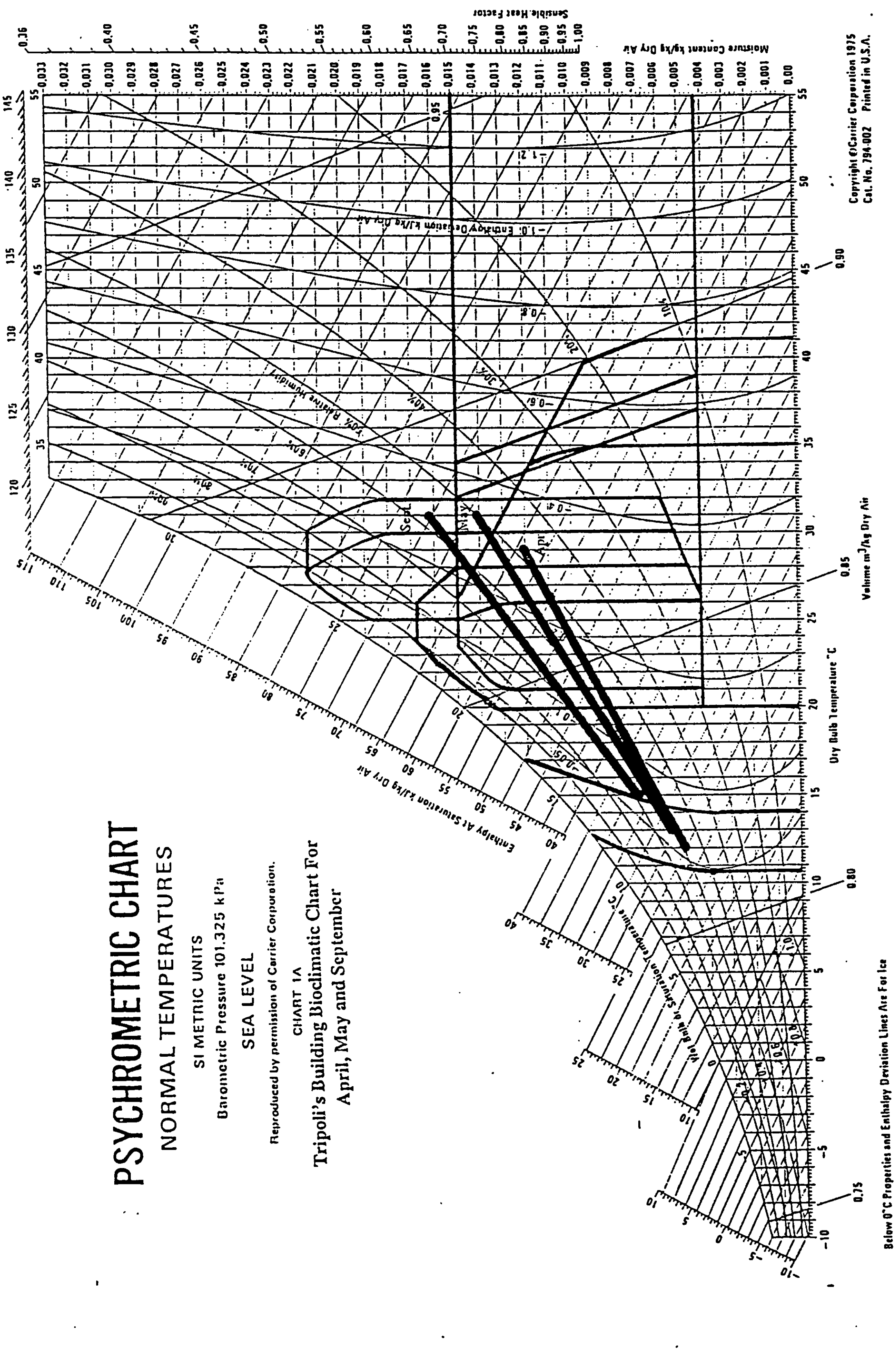

PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Reproduced by permission of Carrier Corporation.
CHART 1A
Tripoli's Building Bioclimatic Chart For April, May and September
Copyright © Carrier Corporation 1975
Cat. No. 794-002 Printed in U.S.A.
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice

Figure (31d)

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4.0 BUILDING SYSTEM

4.0 BUILDING SYSTEM:

It is argued that to make a building is to create a system linked to its surroundings, subject to an interaction affected by seasonal and daily changes in climate and by the varying requirements of man in the time and space of a particular cultural context. The basic concept in dealing with the building as a system is that responses must be provided to the impact of local weather especially in terms of space heating and cooling.

A passive solar heating strategy requires a knowledge of the collection of the sun's heat through the building envelope, the storage of the heat in the mass of the walls and floors, the distribution of heat in the living spaces, and the retention of heat within the building.

The cooling strategy, however, is based on how to protect the building from direct solar radiation, how to minimise heat gains from external and internal sources, and the concepts of ventilation, which will promote natural cooling.

This chapter will explore the design requirements for comfort in two stages: first, by studying the envelope as a modifying layer, and its elements, that is wall, roof and floor materials, and its opening which is doors and windows including shutters; second by studying passive cooling and heating strategies.

4.1 BUILDING ELEMENTS

The building system is explored under separate headings for the purpose of examining the major components of this system as thermal parameters as well as design elements:

1- Building's form and orientation.

2- Building's envelope, (Thermal and other properties of the materials.)

3- Openings and shading devices.

4.1.1 Form and orientation

There are two major criteria of the local climate that guide the form and orientation of a building:

a) Solar radiation.

b) Air movement

These two components have provided the notion of 'optimum shape', which is the shape of a building that has minimum heat gain in the summer and minimum heat loss in the winter.(Olgyay, 1976: p88).

a) Solar radiation.

Solar radiation, which may also be considered in terms of external solair temperature, affects the form of the building. By controlling the ratio of heat loss to gain through the exposed surfaces, Evans argues (1980: p59) that the volume of the building will be very approximately related to its thermal capacity (its ability to store heat energy), while the surface area will be related to the rate at which building gains and loses heat energy. The ratio of volumes to surfaces is highly significant in the configuration of the 'optimum shape'. The orientation of a building is a related design parameter. Total irradiation of a building can be controlled by attributing certain values to this parameter. Therefore careful scientific orientation, in the fullest meaning of the term, will influence almost every structural or mechanical specification for a house, from size and location of the windows to cooling and heating load. In order to select the optimum orientation, one should consider both sun path and the direction of the prevails winds.

b) Air movement

Air movement is an important aspect in shaping the building. For example, by controlling the depth and section of a building of a building, it is possible to increase the rate of day/night cooling by cross ventilation and / or stack effect, at least at time of the year when the night temperature drops to a level when this is viable. The boiclimatic chart described in the previous chapter have clearly shown that in a hot humid climate air movement is essential factor to provide thermal comfort. and this is valuable in itself even if conditions are not such that the temperature or RH drops . In summary, air movement may or may not assist in cooling, but should always improve comfort given Tripoli's particular climate.

The optimum orientation and shape for Tripoli's climate .

Tripoli is a good location to exploit passive solar direct gain to displace a modest winter space heating load. Overheating in summer is more problematic. with steep solar altitudees for much of the day, the roof is vulnerable target. By adopting a two rooms deep plan and 2 story form, the area is minimised and the day-rooms are protected by sleeping rooms. Hight is also useful to exploit thermal buoyancy.The potential disadvantage of two room deep plan, that of roughly equal east and west facades to the north and south, is simply dealt with by orientation of windows.

Thus the shape encourages movement of the air through the building in summer. The additional problem fairly high humidity with high temperature cannot be addressed by orientation and shape alone.

4.1.2 Building's Envelope (including thermal and other properties of the materials)

Having defined the building's geometry the material of its extend envelope affects the heat exchange from the internal environment to the extant environment. The relevant thermal properties of the material are summarised in table 4.

Property	Symbol	Units	Description
Density	ρ	kg m^{-3}	Mass per unit volume
Specific heat capacity	c	J kg^{-1} K^{-1}	Thermal capacity per unit mass and unit temperature difference
Volumetric specific heat capacity	ρc	J m^{-3} K^{-1}	Thermal capacity per unit volume and unit temperature difference
Conductivity	λ	W m^{-1} K^{-1}	Thermal transmission in unit time through unit area for unit temperature difference between surfaces
Resistivity	r	m K w^{-1}	Reciprocal of conductivity (1/ K)
Conductance	C	(k/thickness) W m^{-2} K^{-1}	Thermal transmission in unit time through unit area for a material or component of given thickness for unit temperature difference between surfaces
Resistance	R	(thickness/k) m^2 KW^{-1}	Reciprocal of thermal conductance
Transmitance (U-value)	U	W m^{-2} K^{-1}	Thermal transmission in unit time through unit area for a given element of construction including surface resistance for unit temperature difference
Surface conductance	C_S	W m^{-2} K^{-1}	Thermal transmission in unit time and area through surface in contact with air due to convection and radiation per unit temperature difference
Surface resistance	R_S	m^2 KW^{-1}	Reciprocal of surface conductance
Emissivity	ε		Rates of thermal radiation from surface to that from same area of full emitter
Absorptivity	$\propto$		Preparation of incident radiation absorbed by surface.
Diffusivity	$D = \lambda/\rho c$	m^2 $.s^{-1}$	Conductivity divided by volumetric specific heat capacity.
Admittance	Y	W m^{-2} K^{-1}	Reciprocal of impedance of an element to cyclic heat flow
Thermal capacity	c/ρ	$J.K^{-1}$	Thermal capacity of a given element per unit temperature difference

Table (4) (after Burberry,1981: 65) Thermal Properties of Materials

The value of heat losses and gains and thermal damping and time lag through the envelope is defferent for each element i.e. walls, roof and floor.

1) Walls and roofs

The heat transfer through the building envelope by conduction, radiation and convection is controlled by the main thermal properties of materials conductivity, thermal capacity and obsorptivity. There are five thermal measures or indicators which are useful to describe the way in which the envelope will modify internal conditions.

a- U-Value (Thermal transmittance coefficient).
b- Admittance Y value.
c- Solar Heat Flow Factor
d-Time Lag
e- Damping and decrement factor.

a-The 'U' value; or air to air transmission, is "the thermal transmission in unit time through unit area for a given element of construction including surface resistance for unit temperature difference". The U value is fond by taking the mathematical inverse of the sum of thermal resistance, where resistance, R, is the product of thickness(m) and the resistivity (mK/W) or the product of thickness(m) and the inverses of conductivity (W/mK).

Thus **Uvalue=1/ΣR** (W/m^2K). where (**R= r * th**) or (**I/λ * th**) and the heat flow through the material per unit area, is **Q /A = U (ΔT)** (W/m^2) or **Q/A = 1/Σ**R **(ΔT)** (W/m^2) (where Q= The heat flow through the material, A= Area of the element, r= resistivity, λ = coductivity and th = thickness).

Since the resistance of the material is proportional to temperature drop across it, the computation of U-value also enable a steady state temperature gradiat to be determined i.e. the gradient averaged over a period of time for a particular average inside and outside temperature.

b- The admittance or Y-value is the ability of the surface of a building element to transmit to or from the air at a given rate when the temperature of the air is raised or lowered. The approximate increase in internal temperature of a space is given by the formula:

dt = Q / (ΣA.Y + x)(K)

(dt= temperature increase (K), Q= total rate of heat gain (W), ΣA.Y= sum of admittance of each surface * area of each surface (W/K), **x** allowance for the heat capacity of the air and the heat transfer through windows (W/K).

Effectively Y-value is the Uvalue of the layer of material or layers of thin materials next to the space in question, and the ratio (ΣA.Y+ 0.33 nV) to (ΣA.U+0.33nV) is known as " response factor". This approaches a material value of 1.0 for using thin or light boundary layers; and values over 5.0 signify rather heavy ones. For example, a concrete floor slab will have a high response factor, while a concrete floor covered with carpet will have a much lower one.

c-The solar heat flow factor is the proportion of incident solar radiation which transmitted through a wall or roof element, when the temperature on both sides is the same. This can determined **Qs = q/I.**, where **I(Watts/m^2)** is the intensity of incident solar radiation and **q (Watts/m^2)** is the rate of heat transfer through the material.
The solar factor for a wall or roof is also affected by the colour of the external material, the darker it is the more short wave radiation is absorbed.

d- The time lag is the time delay, for a heat or temperature change on one side of a construction to be transmitted to the other side. The time lag for a homogeneous material subject to temperature fluctuation over a 24 hours cycle is given by (th * 0.023√ 1/D), where D= is the thermal diffusivity (m^2/s) given by conductivity divided by volumetric thermal capacity. The time lag through a multi-layer construction is more complex. It is not simply the sum of the period found for each single layer by the above formula. Mackay and Wrigh (Givoni 1976) have given a relatively simple method based on a "time constant" and CIBSE (A3) give amore complex method based on matrix equations.

e-The damping and decrement factors are respectively the ratio of temperature and heat flux amplitudes on the outside and inside of the construction. Both are again regulated by the square root of the inverse of thermal diffusivity; and for a single homogeneous layer may be found respectively from **exp[-th * 0.00603 √ 1/D]** and **exp[-th * 0.00218 √ 1/D]**. The time constant method for time lag also yield decrement factor for multi layer constructions as stated in chapter 3 the equivalent outside temperature Teo may then be fond

$$\mathbf{Teo = m * (Ti - Tm) + Tm}$$

Where m =decrement factor: The factor by which the rate of heat transmittance resulting from periodic heat flow, is reduced in comparison with the flow which have been expected under steady state condition. Ti = the out side temperature in time lag hours before the time in question, Tm=Daily Mean average temperature. T= The temperature in time of question

The increase in time lag and damping effect is related to the heat storage effect i.e. the thermal capacity of the element " the ability to store heat ",

Thermal capacity kJ/K = V* p*c

Where p= Density, c= Specific heat , V= volume

the ratio of conducttivity to capacity in thermal diffusivity introduces a level of complexity whereby some light materials behave in rather similar way to some heavy ones. For example the time lag for 15cm polystyrene and dense concrete are respectively 3.7 h and 3.4 h, and the decrement factors respectively 0.70 and 0.72. Also relatively light materials give significantly longer time lag and more damping

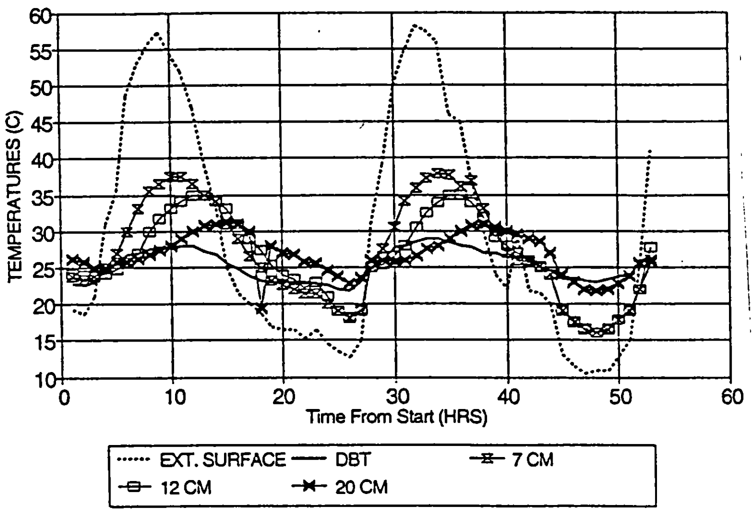
than heavy ones. For example 15 cm cork board with a density of 138 kg/m^3(i.e. much denser than polystyrene) has a time lag of 7.75, more than twice as much as dense concrete or polystyrene; and a decrement factor of 0.48. However the light materials do not have the same volumetric thermal storage capacity- 34.5 kj/m3K for polystyrene, 247.5 for cork slab and 1.371 for dense concrete
So, for example a concrete wall or roof insulated externally with cork could provide a long time lag, and a great deal of thermal damping together with a high level of thermal capacitance.

Therefore the higher the thermal capacity the greater the time lag. This property of the material has significant effect in hot climate, where the maximum heat load at the afternoon will be delayed until the cooler hours at night.

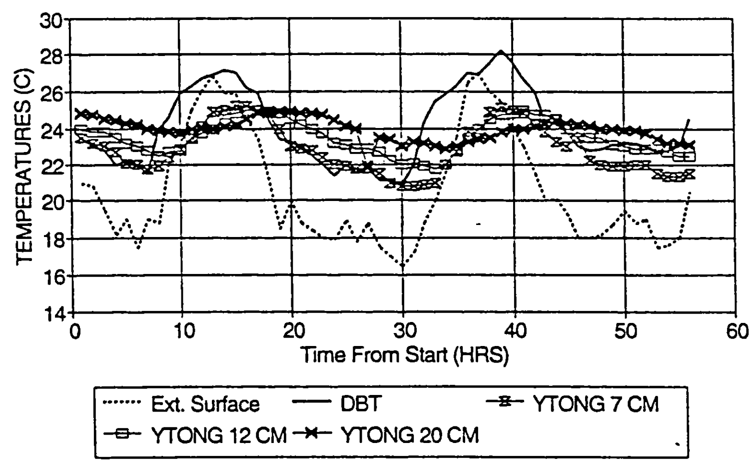
The roof as the most thermally stressed element of the building envelope as well as the one most vulnerable to rainfall, has heightened significance, both in terms of colour and material. For example grass or other form of vegetation will help to protect the waterproof layer below from the under thermal stress; while a light colour on the roof surface will allow it to reflect more solar radiation than a dark one, and consequently keeps the temperature of the surface much lower than would other wise be the case. Therefore it has a great influence on the internal temperature. Figure(32) shows the result of a test that indicates considerable reduction in summer roof heat gain.

2- Floors.

Floors behave according to their level of contact with the ground. Floors are similar to walls in terms of 'emitting and admitting' heat. However the difference lies in loosing or gaining heat, as the heat flux passes through the floor and into the ground as a "heat sink" with most loss to the outside occurring at the floor edge. By adding insulation in this location will reduce the rate of heat loss and gain. Susported or raised floor will tend to function more as a wall or roof, although the "heat sink" effect of the ground still has some influence.
In winter floors may also be major recipients of solar radiation and therefore their admittance and thermal storage capacitance values are significant. In general terms, heavy floor with heavy finishes, plus edge insulation, will provide the best performance. In summer combined with night ventilation, this will assist in depressing excess temperature during the durinal period.



Ceiling temperatures of Ytong roofs, 7, 12, and 20 cm thick, painted gray, together with the outdoor temperature and the average external surface temperature of the roofs.



Ceiling temperatures of Ytong roofs, 7, 12, and 20 cm thick, painted white, together with the outdoor temperature and the average external surface temperature of the roofs.

Figure (32) : After Givoni (1976), The effect of the Roof

Materials study

In the last two centuries many new materials have become available for buildings, some of them exhibit very different thermal properties compared with traditional materials. Burberry remarks that historically the range of available building materials was very limited. and states that "The thermal properties of the materials have been exploited along with the examples of buildings type developed by trial and error". (Burberry ,1981: p64).

Martin Evans states (1980 p49), that materials used as insulation tend to original in cold climates often related to traditional forms of construction in the region where they are applied. In the hot climates the recent adoption of modern constructional techniques has in many cases led to a drop in environment standards compared with that achieved by traditional construction. For example, relatively thin dense concrete roofs provides lower time lag and less thermal damping than a traditional clay/mud mix laid over palm fronds and bamboo or other timber boarding. However, at the same time structural safety, fire protection, and perhaps hygienic standards may well have been improved.

Analysis of Tripoli's Material

In this study the examination of structural material is conducted in two phases:

1- An overview on the traditional materials .walls and roofs widely used in the vernacular architecture in Tripoli.

2- An analysis modern materials (or recently used materials).

1) Traditional materials

Many traditional materials have been proven over trial and error process to be reliable in modifying the climate. In the Old City of Tripoli, thick load bearing walls, are built with a mixture of sand, limestone, ans fibre. The roof is usually built with a layer of palm wood , a thick mud and sand slab, as illustrated in Figure (33). The construction of the wall is done by building two layers of timber for the purpose of shuttering and filling by compressing a mixture of mud, stones, and fibres material. Removal of the shuttering takes place after the mixture is dried. The external surface of the material is then lime washed white. This constructional technique is widely used in the old cities of the country, and is very similar to that in many other Mediterranean locations.

2) Modern materials

There are two types of building material that are widely used in Tripoli's modern buildings: one is concrete, the other is limestone. The typical structural system is a reinforced concrete skeleton, with an in fill envelope. The material of the external walls varies from hollow concrete to limestone. The in fill technique is usually built of one layer of limestone or hollow concrete block with cement mortar rendering on both sides. Reinforced concrete slabs or hollow brick block between concrete ribs are used for the roof Figure (34) summarises the proposed diagrammatic analysis of multi-layer wall in this study:

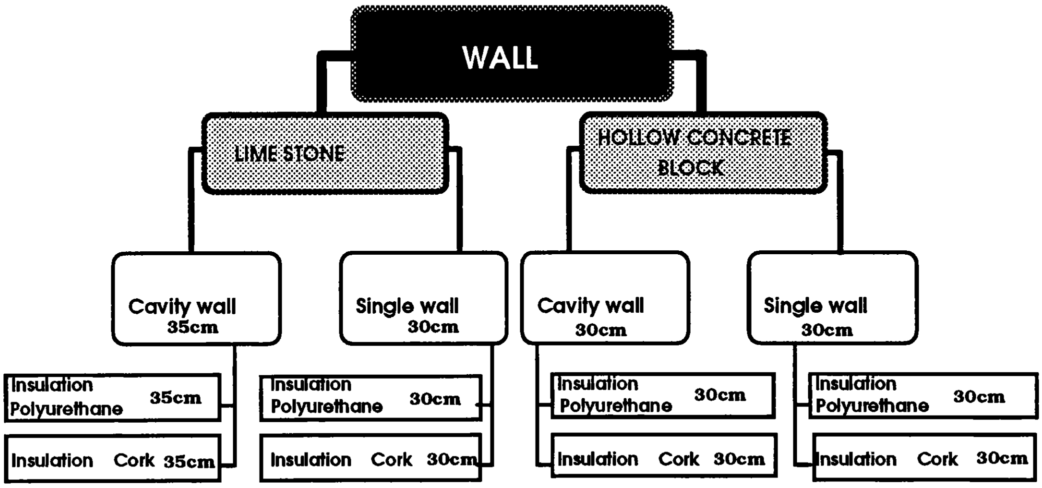


Figure (34): Diagram shows wall material analysis

a-Polyurethane which have been used in the CSES solar house (see chapter 2). "for single and cavity wall"

b-Cork as a green renewable material. (for single and cavity wall)

The analysis of each wall specification is summarised in table5 which gives **Q=Σ AU(ti-eo)(W)**

Where Q= The rate of heat flow, A = Area of the element ,ti= internal temperature, teo= The equivalent external air temperature, as well as the time lag (Φhours) and decrement factor .(f)

From this equation we can illustrate three properties of the material. The Time-lag (according to data of Tripoli temperature the minimum time is nearly 8 hours.) is between, Decrement factor, and the U-value. See Appendix A Figures (from 1- to12). The result is summarised in table (5). The Rate of Heat Flow in to the building, Q is taken through 1m2 of the construction with an estimated internal temperature 27 C. at the peak hot hour (15.00) of the day in June. A passive value for Q indicate heat flux from inside to outside and vice versa for a n negative value.

Type of structure	**Limestone,**			**Hollow concrete block**		
	Q (W)	**Φ**	**f**	**Q (W)**	**Φ**	**f**
Single wall	9.36	4.6	0.36	2.32	5.19	0.45
Cavity wall (Air gap)	6.24	5.5	0.16	2.17	5.6	0.58
Single wall +cork	2.4	5.39	0.16	1.36	6.12	0.22
Single wall polyurethane	1.92	6.3	0.21	0.87	6.12	0.21
Cavity wall+cork	2.32	9.17	0.12	0.75	8.6	0.34
Cavity wall polyurethane	1.88	10.07	0.12	0.63	9.3	0.42

From the analysis the following points are noticed:

1- In terms of Time-lag, the range is from 5 hours to 6.3 for the concrete walls except in the cavity wall with insulation when it rises up to 8.6 - 9 hours. The equivalent external temperature amplitude is smaller than that external temperature since it expresses the damping effect of the construction. It is of great significance since the dynamic heat flow through a particular level such as a wall or roof. The variation of the U value has also a major effect. Therefore The smallest amount of heat flow is through the concrete cavity wall with polyurethane as insulation.

2-Using a cavity wall instead of the single wall reduces the heat flow by nearly half in the stone specification.

3-Adding Insulation reduce the heat flow by nearly half in the case of concrete , while it reduces to a quarter of the value for limestone.

4-The cork as insulation material has an acceptable thermal resistance, in addition to its character as a green material (environmental friendly) compared to the polyurethane.

Most modern roof have a hollow clay pot and ribs structure, concrete and when less ceiling thickness is required a reinforced concrete slab is used.

1- Solid concrete slab

2- Hollow brick pot & concrete ribs .

For the detailed results of the analysis See Appendix (A). Figures from 13 to 18 are summarised in the following table (6)

Type of roof	**Reinforced concrete**			**hollow brick concrete**		
	q (W)	**Φ**	**f**	**q (W)**	**Φ**	**f**
-	6.9	4.38	0.48	3.04	5.76	0.19
Adding insulation, Cork.	1.785	5.4	0.25	1.645	5.4	0.25
Adding insulation polyurethane.	1.47	5.6	0.25	1.365	6.7	0.25

Table (6)

Note that the use of the Hollow concrete block in the roof reduces the heat flow to half, and the insulation materials have fairly smaller results.

4.1.3 Openings and Shading devices:

Windows openings control the level of thermal comfort in building through the control of solar radiation and ventilation by

a) Size and orientation of the opening

b) Glazing material.

c) Type of shading devices.

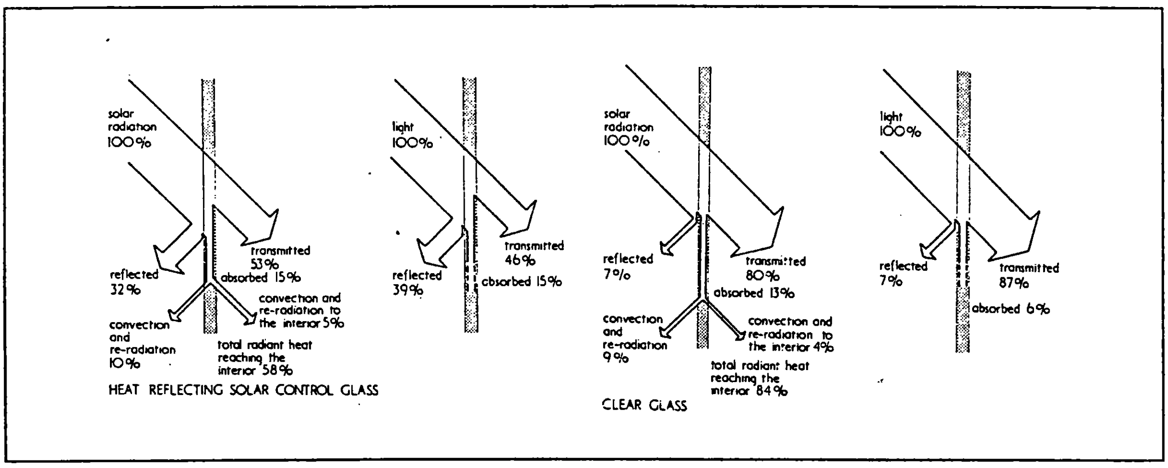


Figure (35): Heat transfer through different glass. (Martin, 1980: p.80)

a) Size and orientation of the opening.

The area of window glazing and openable parts differ according to climate. For instance in winter, the need for solar radiation is more important as temperature is below the comfort zone, and the solar radiation can be used to raise internal temperature, while air movement is not much required, So openings may be fully glazed and partially open able. On the other hand, in summer where solar radiation is not required and air movement is essential, openings must be partially glazed, by means of shutters, and fully open-able.

b)Glazing type

The type of glazing is also very important in controlling heat flow, Figure(35). In order to allow large areas of glazing to provide view and light and in the same time control the amount of solar radiation heat gain, special types of glass may be used absorbing glass (which absorb about 50% of the direct solar radiation and increases the re-emission toward the exterior),or by reflecting glazing

There is development in other high-tech glass such as the photochromic, thermochromic and electronic glasses which modify the incoming rays of the sun so that the optical properties of the glass change in order to control the amount of heat. However, such specification are not only very expensive , and have not very appropriate for dwelling, but they are also inflexible in that they deny useful gain in winter. A pragmatic compromise is normal clear double glazing or double glazing with a low emissivity coating. Trancmission in winter relative to losses to gains a favourable balance; and in summer reliance is on added flexible devices such as shutters, blinds or awnings.

c)Shading devices

Shading to the opening can be categorised as follows, Figure(36)

1- Sunshade as a fixed device. (structure).

2- Adjustable external shading devices (shutters, blinds, awnings).

3- Internal shading device.(blind, curtains).

1-Fixed shading device.

The shape of shading devices is determined by solar geometry, which usually requires a vertical shading device on the east and west, where as a horizontal shading device is recommended on the south exposure. The efficiency of the shading devices is the ability of the shading device to exclude summer sun and admit winter sun

The size of shading device can be calculated by following formula:

$$\mathbf{d = x\ (\tan \alpha / \cos \beta)}$$

d=depth of shading, x is the projection of device→vertical shading, β = bearing(azimuth) angle, α= altitude angle).

2- Adjustable shading devices (eg. shutters)

The use of large opening windows can be practised in any climate with special design details. As Givoni points out "When highly insulated shutters are added to large open-able windows, their thermal effect can be adjusted to varying needs, both diurnal and annually"(1994: p27). Wooden shutters have a relatively high thermal resistance which can be adjusted according to the external climate. Therefore it reduces the heat flow through the glazing and controls the heat gain and loss in to the building. However to minimise the thermal resistance such shutter should be solid rather than comfort, and this excludes both light and air. A compressive might be to have some shutters which are solid and some louvered to allows light and air to filter through.

3- Internal shading device.(blinds)

The internal shading such as blinds is a well tried technique to protect the interior from direct solar radiation In a hot region this method is unsuitable, it efficiency compared with external shading binge low.

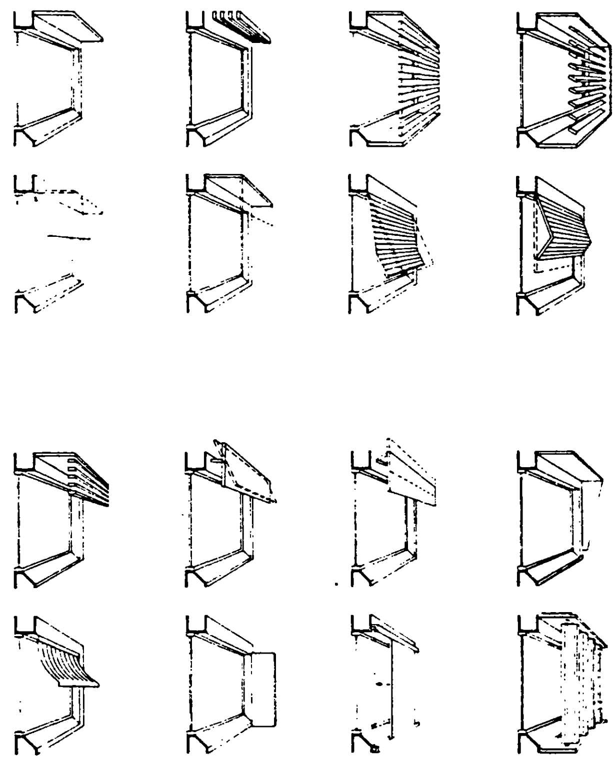


Figure (36): Examples of shading devices

4.2. PASSIVE HEATING AND COOLING METHODS:

The passive technique is one in which thermal energy flows through a building (from collection to storage to distribution)by natural means, enabling the system to function without external power" This has been widely accepted as a definition of passive technology. Passive solar methods have been developed in many ways. However, two major strategies are determined by climatic components of radiation and thermal buoyancy.

1)Solar radiation gain.

2)Natural thermo circulation for cooling and heating (stack effect).

4.2.1 Solar radiation gain which has been utilised in a number of ways

a) **Direct Gain methods.**

b) **Indirect Gain.**

c) **Isolated gain.**

a) **Direct Gain method**: which is based on collecting the solar radiation through large glazed openings to the living space and storing it in the internal thermal mass, This method is particularly appropriate for climate with cold sunny winter, but is also applicable in more temper climates, the criteria being a space heating load which can be displaced or partly displaced by isolate radiation after insulation to an appropriate standard and after allows for free incidental gains.

b) **Indirect gain**, where the solar radiation is first stored in thermal mass, delivery of the energy delayed by the use of 'time-lag' property of the building material. This is an effective way to delay the effect of the intense solar radiation during daytime, and the technique is most appropriate for climate with a strong durirnal solar supply but cold nights, often rather than coastal.

Such a strategy is demonstrated by several techniques.

-**Trombe Michel wall** where the solar radiation can be collected by the glazing located directly in front of a storage mass which can delay the heat delivers up to twelve hours. In fact duirnal dwelling by natural thermo-circulation is also possible by means of adjustable vents at high low level; and in summer the system operates as solar venting "chimney" drawing cooler air through the living space from the north side.

- **Water Trombe,** which operates in the same way as a trombe mass wall but by using contained water as the storage mass, taking advantage of its high thermal capacity.

- **Roof pond,** which operates on the delay of heat transfer through the roof by providing intervenes passive collectors/storage mass (water in black plastic bags) in order to control the heat flow into and out of the building. This technique is appropriate for continental location at relatively low latitudes, and have high solar altitudes, and again by diurnal- natural temperature swings it requires movable insulation as that at night the collector tend is directed to the interior and not lost to the night sky.

c) **Isolated gain** method, where the collector and storage medium are thermally decoupled from the heated interior. Delivery may again make use of air as the medium e.g. a 'thermosiphon' system, with a low level collector charges a rock stone, where once again thermal buoyancy is partnered to greenhouse effect.

4.2.2 Natural thermo-circulation for cooling.

In hot climates, ventilation is a very important means of both reducing the space temperature and maintaining thermal comfort by means of air movement at relatively high temperatures and humidity.

a) Wind scoops (Passive Stack ventilation)

The wind scoop technique is widely used in hot dry zone and there are several different types, according to specific characteristics of weather and local empiricism. Broadly these may categorised as follows. Figure (37).

1-Wind towers or scoops.

2-Wind scoop with connected underground tunnel.

3- solar chimney (enhanced stack effect).

1-The tower is usually oriented towards the prevailing cool breeze (e.g. from sea to land) and directed into the building. The height of the tower depends on the wind speed and direction. The "captured" wind is then directed into the rooms through low- level grilles, sometimes leaving, the rooms via an internal courtyard. However, such systems are not totally relate on wind, since the height differatuly between scoop and delivering grilles as will thermal buoyancy due to temperature differentials, creates a stack effect causing air circulation. This is particularly the case if air temperature is subject to large swings over a daily cycle, while the thermal mass of the building has a much flatter cyclical temperature profile.

2-A refinement of the wind scoop is by passing the tunnel of the wind scoop underground or over water or both, to cool the air before releasing it into the building. This takes advantage of the underground temperature as this is usually less than the surface, as well evaporative cooling which is useful in a hot dry climate. The temperature is able to change water from a liquid state to vapour, the former through a certain amount of heat known as the latent heat of vaporisation, and hence cooling, and humidify the air.

3-A solar chimney uses the sun to heat the upper part of the tower, creating a decrease in the air pressure which cause a vertical movement (Buoyancy forces)for the air.

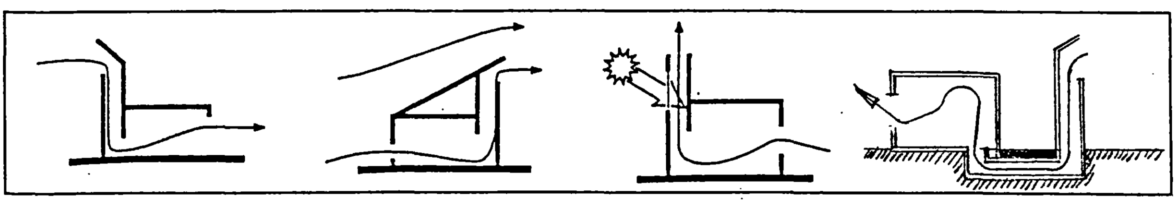


Figure (37): Examples of wind scoops

4.2.3 Earth Passive cooling Techniques.

The use of stable earth temperature for cooling is possible in two ways

1-The earth sheltered house

2-cooling by earth tube.

1 Earth Sheltered house

The idea of using the earth as a passive cooling technique was widely utilised in the earth houses which have been used by ancient civilisation in many parts of the world. In Libya this type of building was built in Gharian to the south of Tripoli Figure (38). Using this technique is expensive and also it neglects the human requirement for natural lighting and ventilation which may effect both thermal comfort and psychological satisfaction. Thus advantages the need for visual contact with the outdoor environment another way of passive cooling is to take advantage of underground temperature in term of air delivers tubes, as in the wind scoop plus tunnel described above.

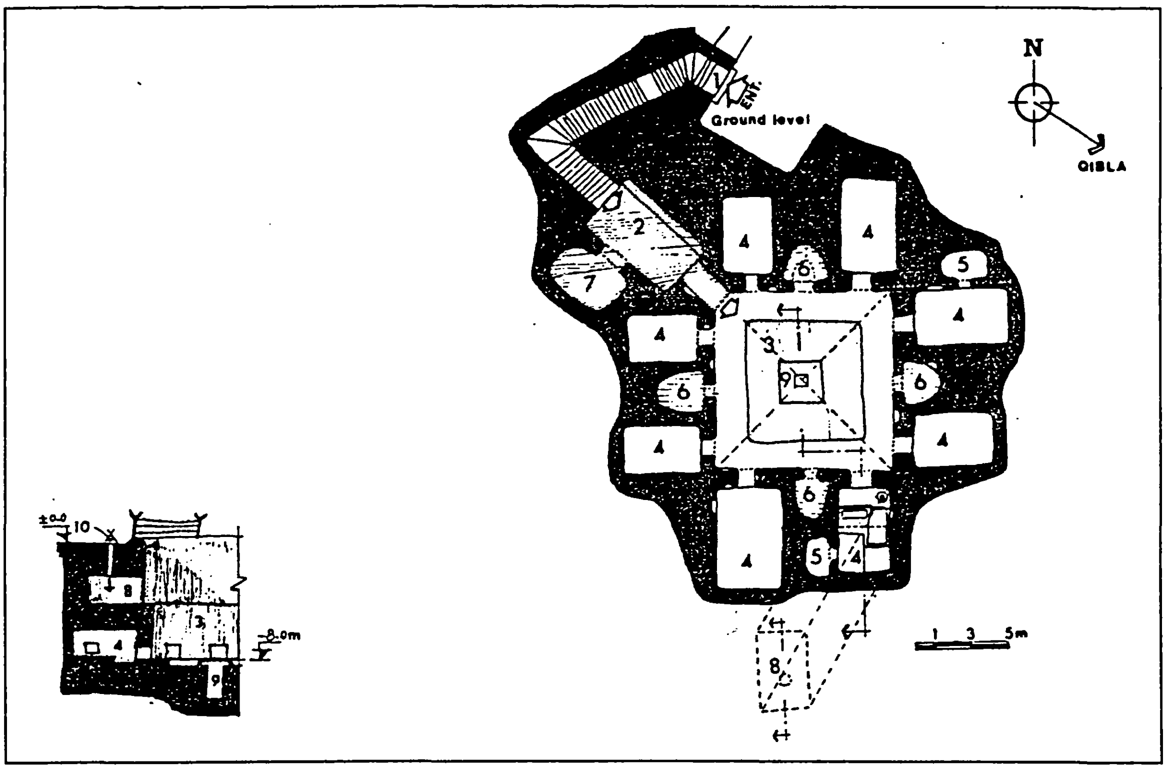


Figure (38): Typical underground house, Gharian, Libya

1:Entrance, 2: Lobby 'Saqifa', 3: Courtyard, 4: Bedrooms, 5:Babies bedroom, 6: Kitchen, 7: Animals space, 8:Upper level storage, 9: Septic tank, 10: Hole 'zimmer' leading to the storage area. Bathroom and Guest rooms are usually on the ground level. (Bukamur. M., 1985 p212)

2 Cooling by Earth Tube

This technique is relatively new in terms of modern application for passive ventilation in hot countries. An early application of a similar concept dating from the 16th

16th century and making use of natural cavities (covoli) in the hills of Vicenza, Italy has been reported by Fanchiotti and Scudo. Cooling by a system of earth tubes relies on exploits the temperature of the soil at a depth of a meter or more that is lower than the daytime ambient temperature, to cool supply air. The system consists of long pipes, buried in the ground, which drawn in warm outside air, transfer heat to the earth and then deliver cool air to the house. In order for such system to passively, an adequate height must be provided and suitable pathways to ensure that dense air leaving at the highest point will cause the dense cooler supply air to circulate through the underground into rooms via low level grilles.

This system not only provides a sensible cooling but also, in hot humid seasons, appreciable dehumidification of the ambient humid air may be achieved.
This depends on two factors:
a) The system's design.(tube's layout, length, diameter and the material of the pipes).
b) The nature of the soil (as it is the cooling resource).

a)The system's design

The length of the pipe is controlled by the required cooling load and the relevance on a dehumidification process. Francis's studies (1981), shows that 70% of the potential cooling from the ambient air to the underground temperature was achieved at a tube length of about 12 meters. This suggests that the length of the tubes should not exceed 15 meters, and that the required overall flow rate should be achieved by increasing the number of the tubes or increasing their size. It has been proved that by increasing the length of the tube from 50m to 70m the temperature dropped only 0.5 K. The temperature exchange decreases in the last 20m.

In terms of dehumidification , in a relatively humid region the increase of length of the tubes beyond the length needed for sensible cooling is preferable in order to increase the amount of water condensation. for example, by reference to a psychrometric chart, if air at 75% RH and 35°C enters the pipe it will state to condense below about 30°C. Its temperature and absolute humidity will therefore fall, the latter consequences lowering the dew point and therefore acting as a "brake" on further dehumidification. The intention of such system is to lower the temperature and humidity to within the thermal comfort at the point of delivery. Clearly if the duct is hygroscopic, so that condense is simply absorbed, rather then collecting as a stream or pool at the end of the duct. The prospects for sensible cooling, without adding back humidity this will be improved loss of moisture to the soil and consequent increased conductivity will further enhance such prospects .

The pipe's diameter controls the air flow rate as well as air speed. and affects the cooling load and the dehumidification process. Barrie (1993, p 47), argues that the larger the diameter (suggested 90 cm) the greater the surface area, and therefore the greater the heat exchange. However, two pipes of 22.5 cm diameter will provide the same volume flow rate as one pipe of 31.8 cm diameter; but the layer single pipe provides a surface area of 1,0 m^2/m run of the pipe, whereas the two smaller pipes provide 1.4 m^2/m run. Therefore several small pipes provide great potential for cooling than a smaller number of large ones, as well as being more economical in terms of purchase cost.
There is also an inverse relationship between the flow rate and the temperature drop of the air. the higher the flow rate, the less time for the air to stay in the tubes and therefore less time for heat exchange, and a relatively higher temperature of the outlet air.

In addition, the optimal flow rate is more complicated in a humid region if there is a potential for dehumidification of the air while it flows in the tubes. It is preferred to lower the flow rate in order to cool the air in the tubes to a temperature below its dew point and thus to obtain air dehumidification. as discriped above.

The lay-out of the pipes is mainly controlled by the site area and the optimum distances between the pipes. There are essentially two ways to lay the pipes, radially and in a parallel pattern with spacing distance ranges from 1.2 meter to 4 meters.

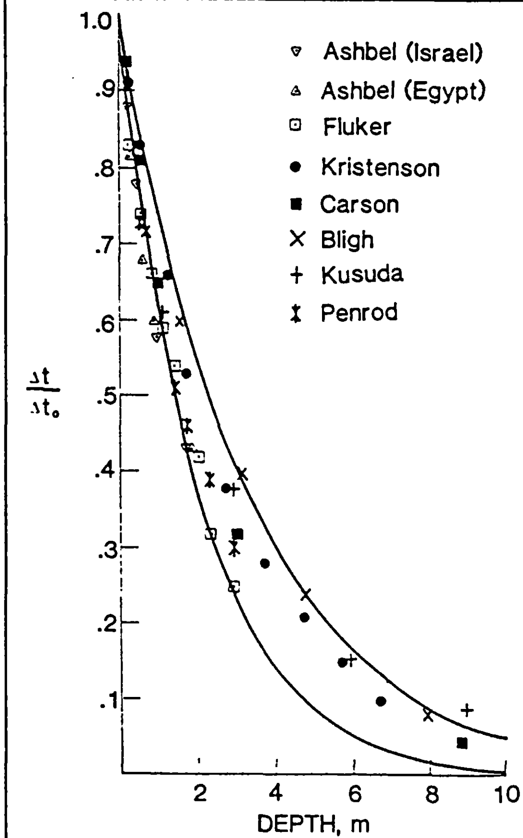
The depth of the tube is determined by the soil temperature. Goulding (1992, p 105) has pointed out the pipes should not buried less than 1.5 m as it is not enough to permit efficient performance of the system, also at depth greater than 6.5 the ground temperature remains practically steady.

b)The nature of the soil.

The natural temperature of the soil is an important aspect on that affect the cooling efficiency of the earth tube. The soil temperature varies with the depth, type of the soil, time, and climate Figure (39).

The temperature of the soil is mainly affected by the thermophysical properties of the material especially it's conductivity, and diffusivity (the ratio of the conductivity to the specific heat capacity), With higher diffusivity heat is exchanged more easily between the surface and the layers below.

The conductivity of the soil varies with the type of the soil, and the climate, the conductivity of soil with a high loam and clay content is higher than in sandy soil, because it has a higher water content. Therefore diffusivity of loam and clay soil would be higher than that of sandy soil. In the following table (7)



Relative temperature range (dT/dT_o) as a function of depth. Various experimental studies.

Figure (39):Relative temperature of soil (Givoni, 1994)

	Soil Type		
Climate	Loam/clay	Intermediate	Sandy
Desert	0.45	0.50	0.55
Arid	0.40	0.45	0.50
Intermediate	0.35	0.40	0.45
Humid	0.25	0.35	0.40
Wet	0.2	0.30	0.35

Table (7) Diffueivity variation with type of the soil.

High solar radiation on the surfaces cause a high diurnal range of the surface temperature, and the annual pattern of precipitation affects the thermal conductivity of the soil.

In a hot climate where maximum air temperature is above 35°C, a temperature for the soil of about 24°C is acceptable .In many hot regions cooling the soil to such a temperature is achievable by special treatment to the surface, Figure (40).

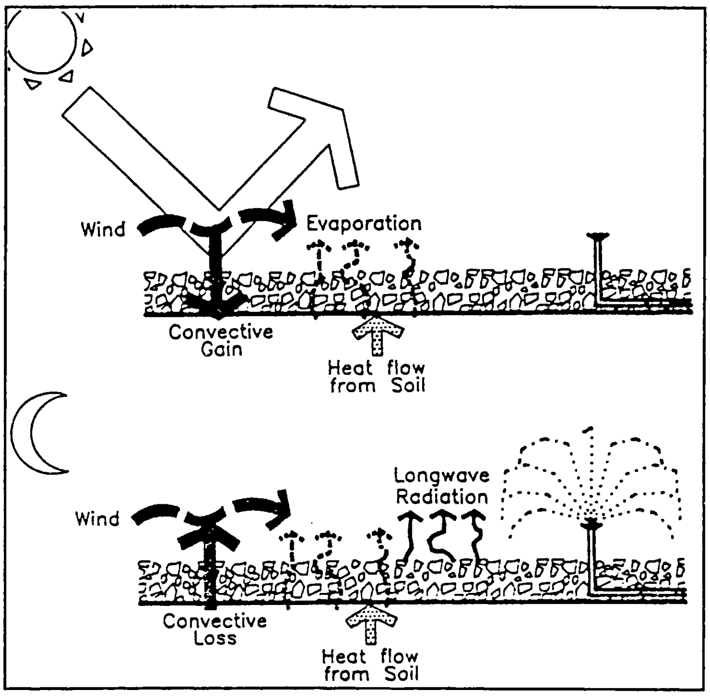


Figure (40): Thermal balance of wetted soil covered by a mulching layer. (Givoni, 1994)

The natural temperature of the ground cover controls the temperature of the surface. According to Kusuda, this varies according to the different surface treatments.(Table,8) The maximum surface temperature at1.2 on depth could be lowered by 5.5 K if it is covered by long grass rather than bare soil.

		Depth level (meters)of the soil				
Treatment		0	0.3	1.2	3	9
Black Asphalt	Max.	32.8	30.6	26.1	20	13.3
	Min.	-1.7	0.6	2.8	8.9	11.1
	Mean	15.6	15.6	14.4	14.4	12.2
White Asphalt	Max.	25	23.3	19.4	15.6	12.8
	Min.	-2.8	-2.2	2.8	7.2	10.6
	Mean	11.1	10.6	11.1	11.4	11.7
Bare Soil	Max.	25	23.2	22.2	17.2	13.3
	Min.	-2.2	0	1.1	6.1	10.6
	Mean	11.4	11.7	11.7	11.7	11.7
Short Grass	Max.	23.9	20.6	17.8	16.1	13.3
	Min.	-0.06	1.7	3.9	8.3	11.1
	Mean	11.7	11.1	10.9	12.2	12.2
Long Grass	Max.	21.1	18.3	16.7	16.1	12.2
	Min.	-2.2	1.1	3.3	7.8	10.6
	Mean	9.4	9.7	10	11.9	11.4

Table (8) . Maximum and minimum soil temperature (C) with different surface treatment (After Kusuda)

Also according to experiment by Givoni the temperature of the soil can be modified by covering the surface by with a mulching layer such as bark chips or pebble. This affect the thermal balance at the surfaces and modifies the radiation balance, connective exchange, and evaporative cooling of the soil .

The result of this experiment has been plotted on the following charts , showing the Daily temperature patterns in a desert in Israel at depth level of 10, 30, and 60 cm , for bare soil and moist soil covered by pebbles. Figs (41,a,b)

The efficiency of the tube system

Terry S Bout (1987) argues that this system has a limited cooling ability " if the system functions continuously, it will exhaust the earth's ability to absorb heat, usually within an hour *(Air movement p 161).* On the other hand Scott, Parsons and Koehler's study (Givini1994) indicated that "the effectiveness for tube during a week with continuous operation is about 66%, which could be increased with intermittent operation up to 80%.

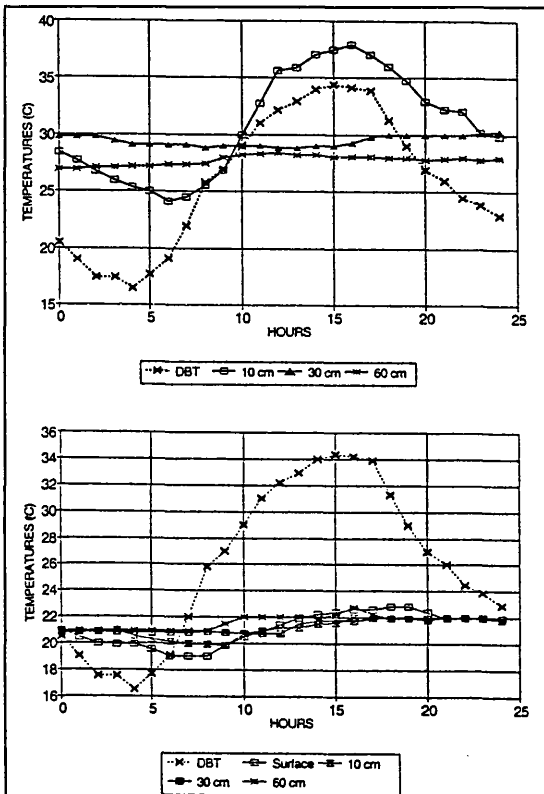


Figure 41:a,b): Diurnal temperature patterns in a desert

The soil next to the tube is able to regenerate it's cooling potential during the nigh. This is calculated by the following formula.

E = (inlet temp.) - (outlet temp.) / (inlet temp.)- (undisturbed soil temp.).

where E = effectiveness for tube

The Expected cooling

In predicting the cooling load of this system a few studies have been done each related to a certain climate or system type. In this study the calculation of the predicted cooling is done by two methods based on pervious field studies.

1-According to computer simulation (regression analysis) developed by the Princeton Energy Group (PEG): The predicting cooling potential of their "cool-pipe" system can be determined under the same conditions , by the following (formula)

Expected cooling (kWh) = 0.8*F + 2.54*D + 16.1*L + 28.5*Cond + 0.92*HC

Where F= air flow (m3/hr), D= Diameter (cm , L= Length (m), Cond= Soil Conductivity (w/mc), HC= Soil Heat Capacity (wh/m3C)

This formula is for predicting expected cooling from a pipe in the ground (at a depth of 1.2 m) in the climate of New Jersey with the (initial ground temperature at 10°C, summer design 31°C dry bulb temperature and 23°C wet bulb temperature, and 538 degree days of cooling.

2-According to experiment done by Gestate, Peterson and Muehling (1983):
Here the climate is nearly similar to that of Tripoli (as maximum external temperature rises up to 40.6°C and summer is dry with high humidity. Whit 8 pipes, 30 m long and of 25cm diameter, air velocity 1.1 m/s flow per tube 204 (m3/hr) and soil temperature is 24°C, the expected peak sensible cooling load is about 19.7 W/m.

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5.0 ENERGY EFFICIENT MODELS.

ENERGY EFFICIENT MODELS;

The history of human settlements, is system with apparently effortless examples of energy efficient design (i.e. without the involvement of an architect). As a climate modifier, modern buildings have tended to performs less well than traditional vernacular forms, which responded to regional or local constraints of the climate, availability of materials, social and defensive needs. The philosophy underpinning 'the international style' inevitably resulted in buildings being over-reliant on fuel-guzzling 20th century technology. This has been exacerbated by financial properties. The purpose of this vale is to use an analytical approach to reduces this situation with respect to a housing prototype which is minimally reliant an auxiliary energy for heating and cooling.

In this chapter, it is relevant to briefly examines the example of the indigenous architecture of the Old City of Tripoli followed by the proposed model of CSES, where a brief description and aims of the project is stated. Certain questionable design aspects also highlighted with the respect to the latter. The model is proposed by the author will then focus on how an energy efficient design can accomplish a successful interaction between the three systems of environment, humans and building.

5.1.1 Vernacular: A pragmatically derived architecture.

Climate as a design constraint has a significant role in the development of a number of design principles in vernacular architecture. This is born out in the period prior to the last two hundred years, close attention being paid to climate in all buildings. This seems to be the distinctive quality of the architecture in the Old City of Tripoli, where through a process of trial-and-error over generations, a number of successful design principles have emerged. For the purpose of the study, the discussion on these principles will be limited to three vital design elements: Courtyard, Building envelope, and Fenestration.

a) Courtyard ;

The courtyard as a design element dominates house design in the old city of Tripoli. Houses have always been built with a concept from inside out. Courtyards form the

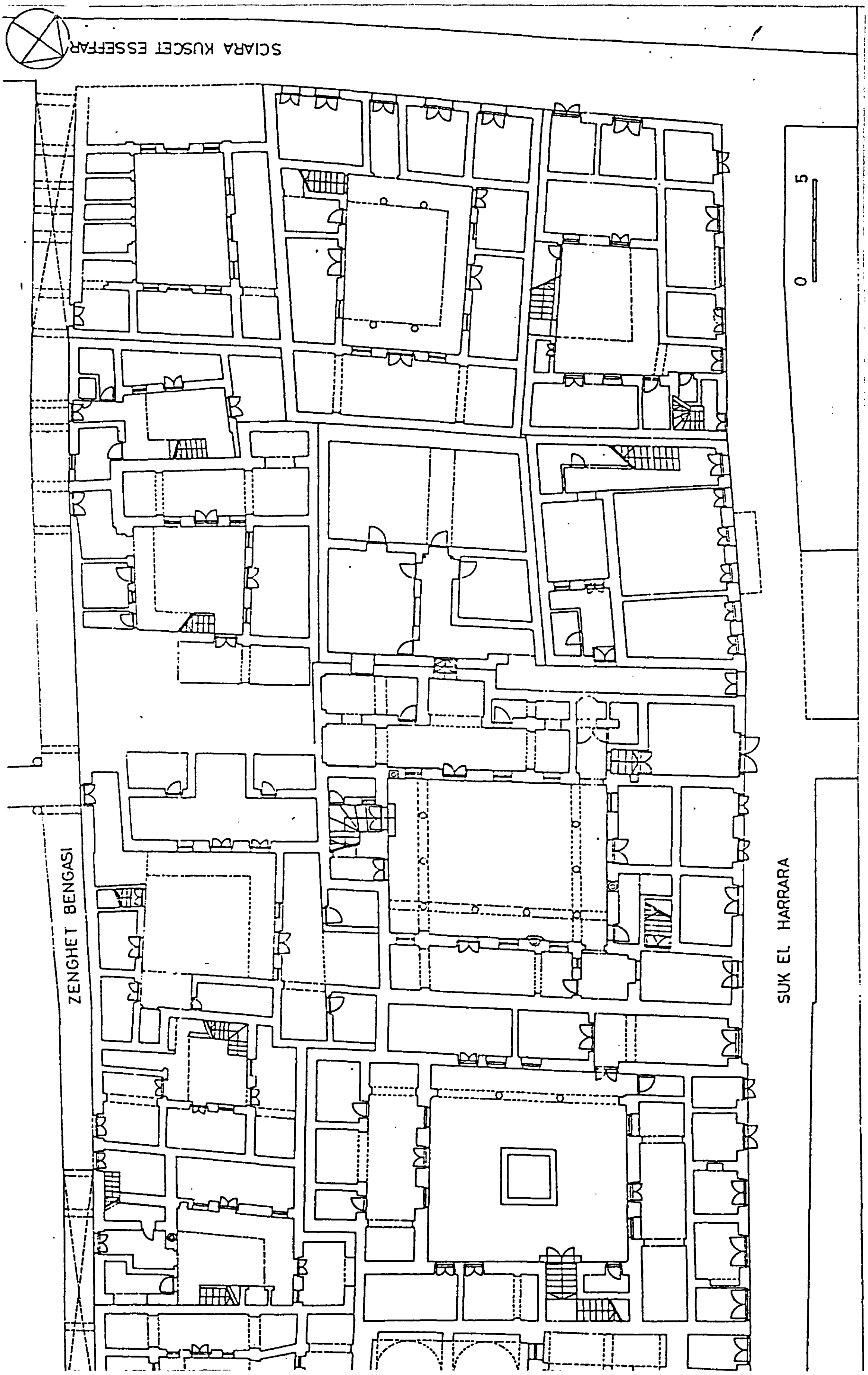


Plate (1): Ground Floor Plan of a sector in the Old City of Tripoli, After Expert Report, Tripoli's Municipality, 1982

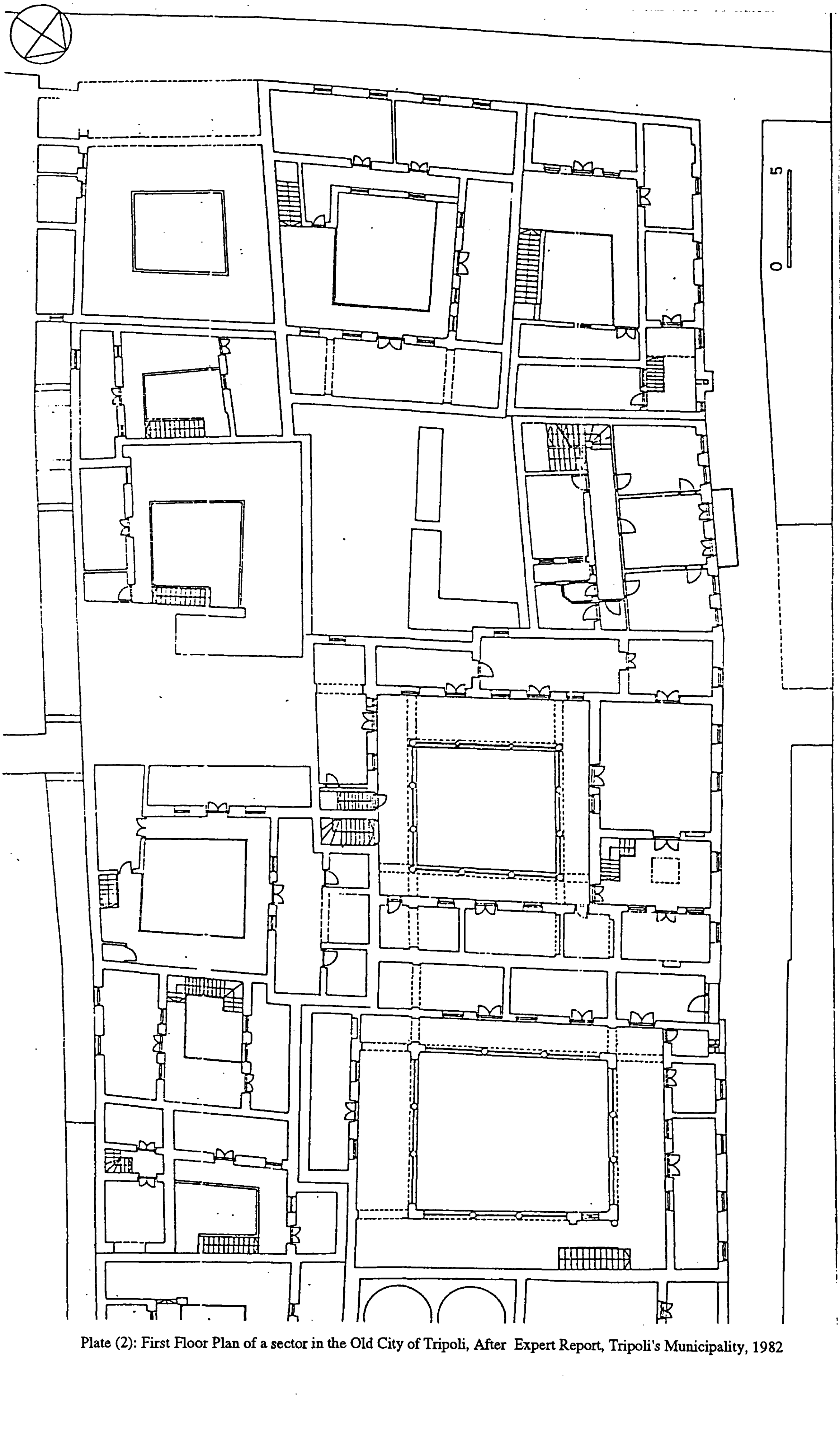


Plate (2): First Floor Plan of a sector in the Old City of Tripoli, After Expert Report, Tripoli's Municipality, 1982

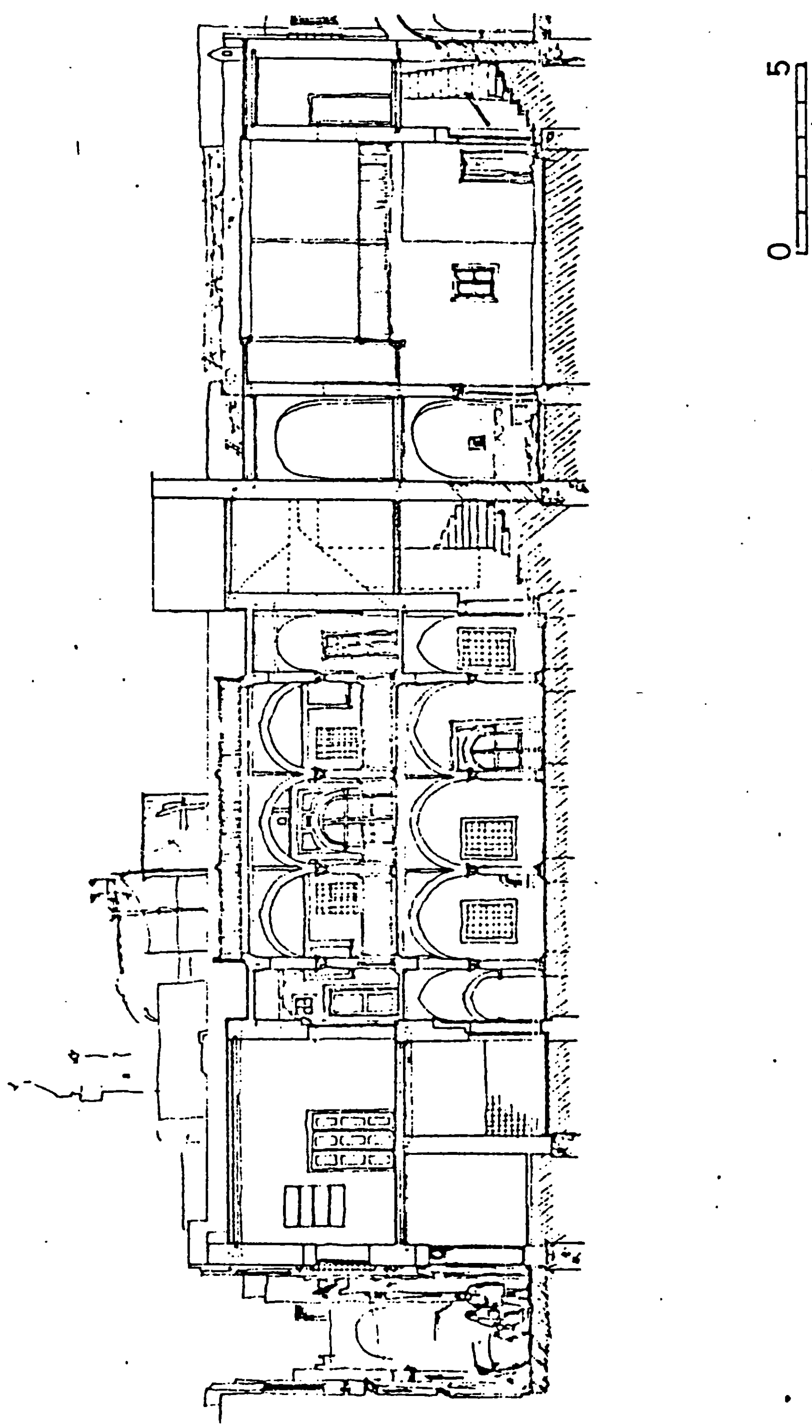


Plate (3): Section in a typical court yard house in the Old City of Tripoli, After Expert Report, Tripoli's Municipality, 1982

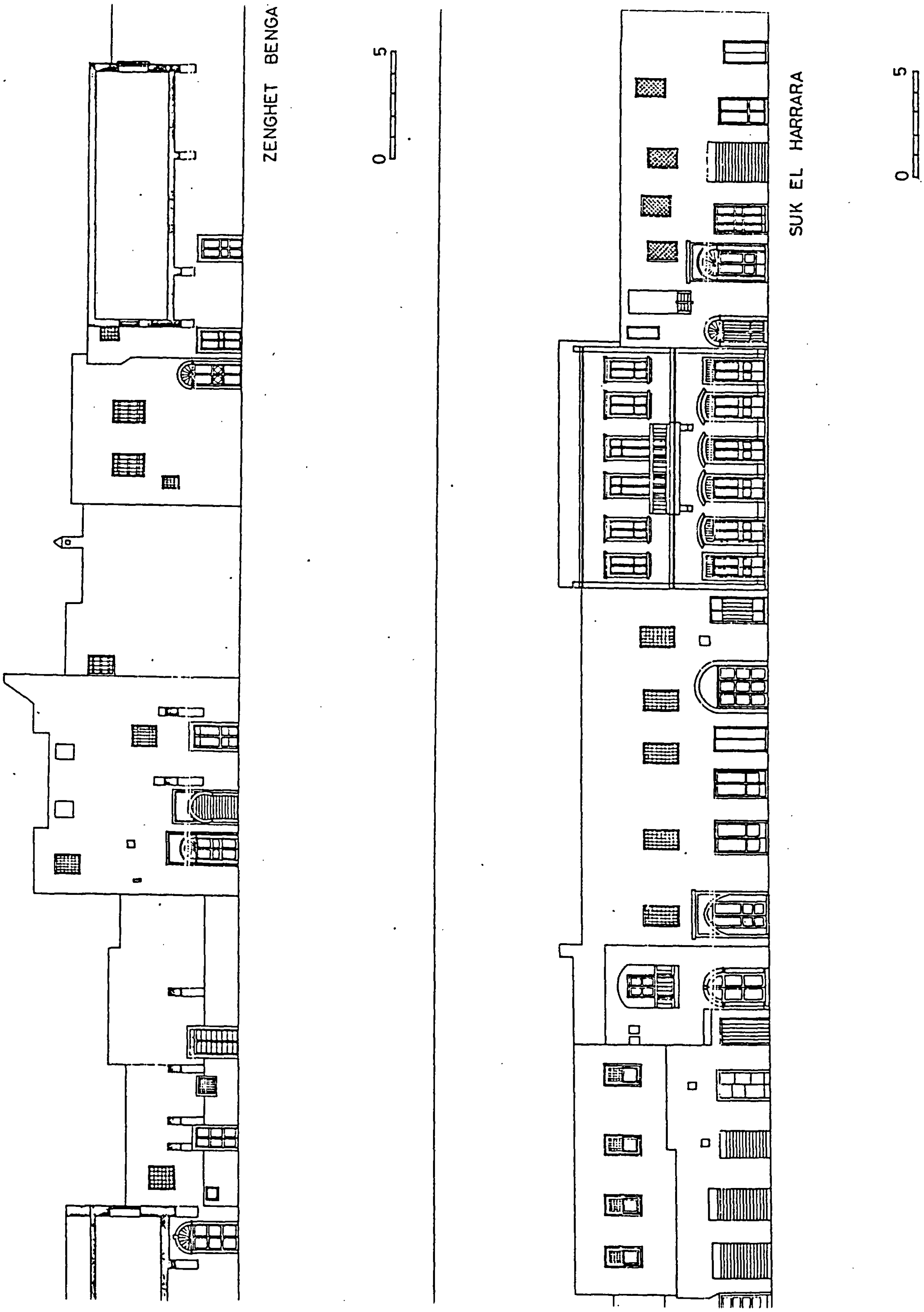


Plate (4): The elevation of 'Zenghet Benghazi' and 'Suk El Harrara, the Old City of Tripoli, After Expert Report, Tripoli's Municipality, 1982 departure point of the design, that is the core of the spatial arrangement of other spaces of the house. The average total area of a house is a generous $140m^2$ to $350m^2$. It usually consists of one or two stories with a number of rectangular bedrooms. bathroom, kitchen and one or two guest rooms. Most of these spaces are oriented towards the open courtyard, but, guest rooms and toilets are usually related in their position to the street. The entrance of the house opens to a corridor which turns through 90 degree from the street for the purpose of privacy, while the staircase and the bathroom are usually located near the entrance. Finally the roof is also used for many purposes, such as drying laundry and fruits and collecting the rain water into tanks. Plate (1) and (2) illustrating sector of the urban fabric of the Old city of Tripoli.

As a result of the pressure of modernisation, the courtyard house has gradually disappeared. The courtyard functions as a passive cooling system; its small enclosed area acting as a sink when the cooler nocturnal air is trapped and flows into the rooms at low level, while the warm air moves out of the room at a higher level. The height of the courtyard is usually bigger than its width and length, to assist shading. The second floor is also normally bounded on two or three sides by a terrace with low arcades which shade the main facade and openings.

In considering it's potential, it is arguable that conceptually the cycle of air movement in the court yard is a design principle that can be applied and referred in many ways. It's location, however has to be central to other spaces, and it therefore impress large houses which in turn relates will to a particular extended family structure. Plate(3).

Culturally, the courtyard as a space is the common living room, and for this purpose it has been enriched by vegetation which provides more shading.

b)Building envelope.

The external envelope of a building is examined in this study as two related components. First is the walls. Second, is the roof. Both components in traditional architecture are will adapt and to the climatic constraints.

1) Walls:

Two important elements in the external walls are highlighted here: first is the material/structure and second is it's surface treatment.

Structurally traditional buildings have been built with a load-bearing system, of fairly massive walls, some (40-80cm) thick. Different materials were used in these construction However, Limestone, has been widely used. This thickness provides a suitable thermal time lag to delay the heat flow into the building to the cooler night-time.

Second the surface treatment in terms of rendering material and colour has had a significant impact on its thermal performance. The white lime wash has proved to be an excellent solar reflector and has the same ability as any other colour to emit long wave radiation to the night sky. In addition, this has established the image of the white city as a neutral background for richly detailed ornamental surrounds to windows and entrances, Plate (4).

2) Roof:

The typical roof is made of wood or palm trunks used as beams and covered with palm leaves and topped with a sun-baked mud/sand slab. This has also developed a massive roof with a thickness of 30- 40 cm, as well as short spans. Thus as the volume of space is required to be as large as possible, the height of the roof is extended to 3-4 meters. This is basically to provide space for the hot air in the room. Parapets are usually high enough to provide privacy, and shading may be provided by vines that climb from the ground to a roof pergola.

c) Fenestration.

The urban fabric of the old city of Tripoli is characterised by its compactness. Houses, as a result have shared walls, where there is typically only one facade facing the street. Accordingly, a limited possibility of having openings on the street has emerged. Most of windows are towards the court yard.

Due to limited technology as well as the climatic influence, openings generally tend to be small in proportion to the surface area of the wall. Together with the 'mashrabia' which is a type of shutter that allows ventilation while bolding solar radiation, This has developed an architectural image that has its own aesthetic quality-an elegant dialogue between these detailed openings and the massive simple white external surface, as illustrated in Plate (4).

It is arguable that within this treatment there may be valuable design elements that can be utilised in establishing a modern architectural language that responds to both environment and cultural criteria. However, the since local architects tend to neglect these principles. The modern house in Tripoli has no courtyards and has relatively larger openings. Consequently, the city has lost its image and climatic control has become based on air conditioning and other mechanical means.
The look of the courtyard is a consequence of several factor. Planing poling and modern expiration jointly with individual plots; the extended fairly is not so prevalent and generally economic favour a building with space around it rather than a space with builds around it. Neither the CSES proposed nor the model of the Arthur try to reverse this tend. Rather explore the possibilities for a house which is climatic appropriate as an object on plot.

5.1.2 The Solar House , A proposal of the CSES Tripoli.
As part of its experimental energy efficient work, the Centre for Solar Energy Studies, CSES, has developed a 'Solar House'. The project is located in Tripoli, and its aim is to provide a references for Libyan researchers and architects to consider energy efficient in their designs.

a) Overview;
In the design process of the solar house, two systems were utilised: First are architectural solutions, in which some passive principles have been applied. Second is the mechanical system in which active solar principles have been introduced. The solar collectors make a clear aesthetic statement on the front elevation while passive features are less apparent.

Functionally, as illustrated in Plates(5, 6, 7 and 8), the solar house has a mixture of different zones of activity: First, the basement occupies almost 1/4 of the floor area, and it is reserved for electrical and mechanical utilities. Second, the ground floor, which is the main floor, is reserved for the residential purpose that consists of entrance, guestroom, kitchen, living room and three bedrooms. Finally the first floor is inhabited by offices. Therefore, by its nature this is a mixed development, and although it may be used as a reference for techniques, as complete model it is not representative of a typical house.

b) The Passive Techniques.

For the purpose of the study, examination of this model will be limited to the passive techniques. The building's layout is linear with a depth of two rooms, and has a north south orientation, However, the north and south facades have several projections and inshot so that this is a house with a large perimeter relative to its enclosed volume. The concept of a wind scoop is applied in the design through the staircase which is oriented towards the North, and located in the middle of the building. This may either permit exhaust of warm air by stack effect or at other times ingress of cool air, the stairwell and corridors acting as distributes to the rooms in each case.

Thermal insulation is proposed as a part of the external walls, Therefore, the building envelope delays the day heat to the night-time where the opening and stair tower allow ventilation to cool the building. The glazing areas have fixed structural shading, Plate(9).

However, there will restrict useful passive gains to south facing rooms in winter. The maximum hourly heating load has been estimated as 11.039W, while the estimated maximum cooling load is 18.805 W.

c) Analysis;

The appraisal of the CSES solar house focuses on certain design aspects,

1-The mixture of domestic and business activities may be seen as a negative point, as each function generates its own thermal requirements. For example, the first floor offices will generate heart during the day in summer-gains from computers, people etc.- so that the bedrooms below may be adversely affected overnight..

2- The building's linear layout may be considered as a positive point for ventilation, but the detailed planning results in an unfavourable surface to volume ratio. There is also a large area of roof exposed to the effect of solar radiation, some of which is directly over day-time living accommodation. Therefore, summer evening comfort in these main rooms is very dependant on the time lag of the roof construction, which would required to be over 12 hours in order to be effective.

3-The passive cooling technique is mainly based on the staircase tower. This system requires a careful design of height and size, which seems is not the case. Moreover, even supposing that the system of distribution function as intended the temperature and humidity of night air during peak summer period is such that nocturnal cooling is unlikely to be effective. Air movement may be assist comfort, but the fabric of the building will stay at a relatively high temperature.

4-The effectiveness of the shading devices is limited both by their structural nature and their high thermal capacitance. Hot air rising s near the glazing will accumulate by the shading devices which is undesirable. Plate (9).

5-Generally, the size and shape of this building seems to generate more problems than solutions and as a consequence its aesthetic image as an energy efficient model is elusive. plates (10,11).

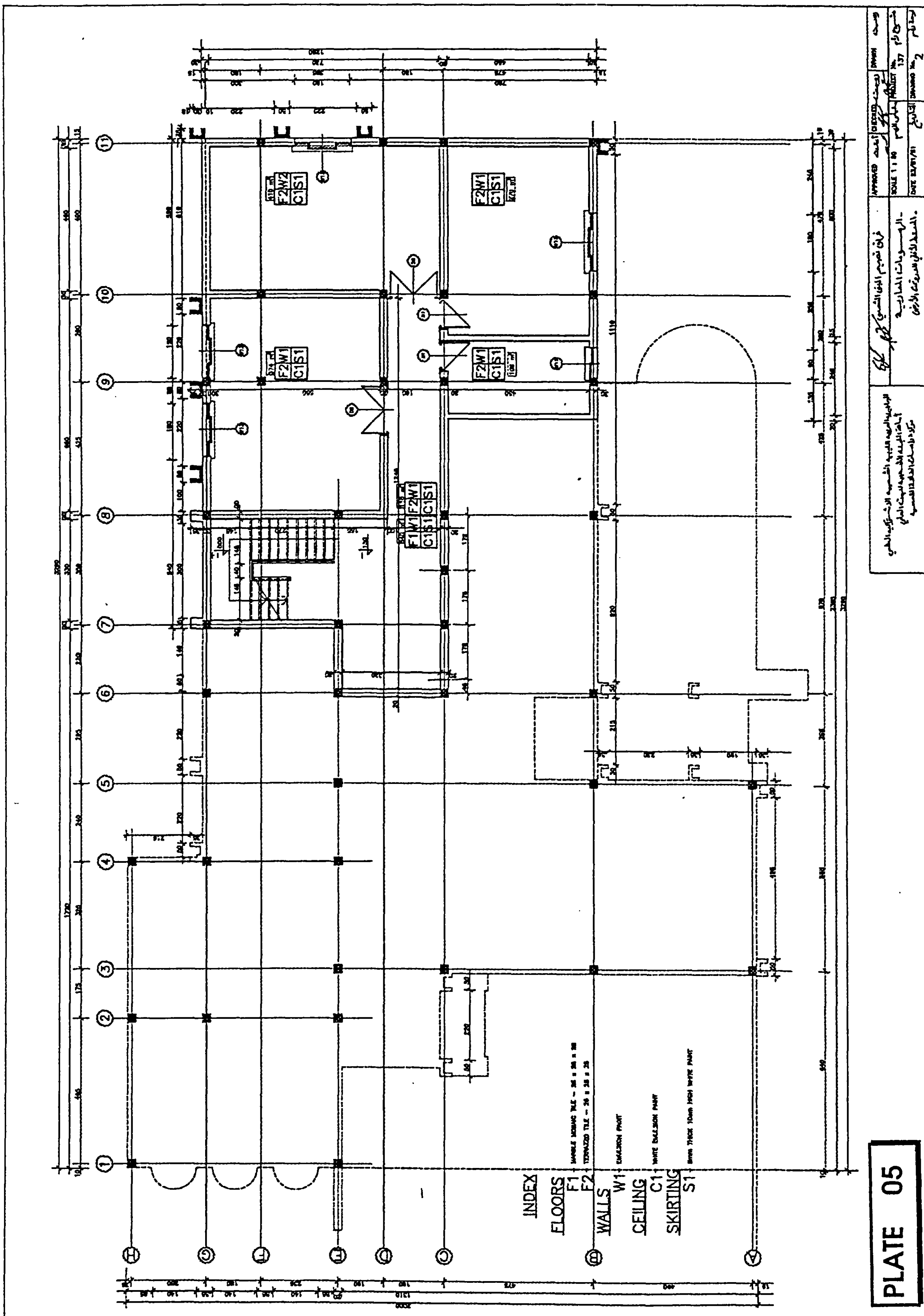


PLATE 05
INDEX
FLOORS
F1
F2
WALLS
W1
CEILING
C1
SKIRTING
S1

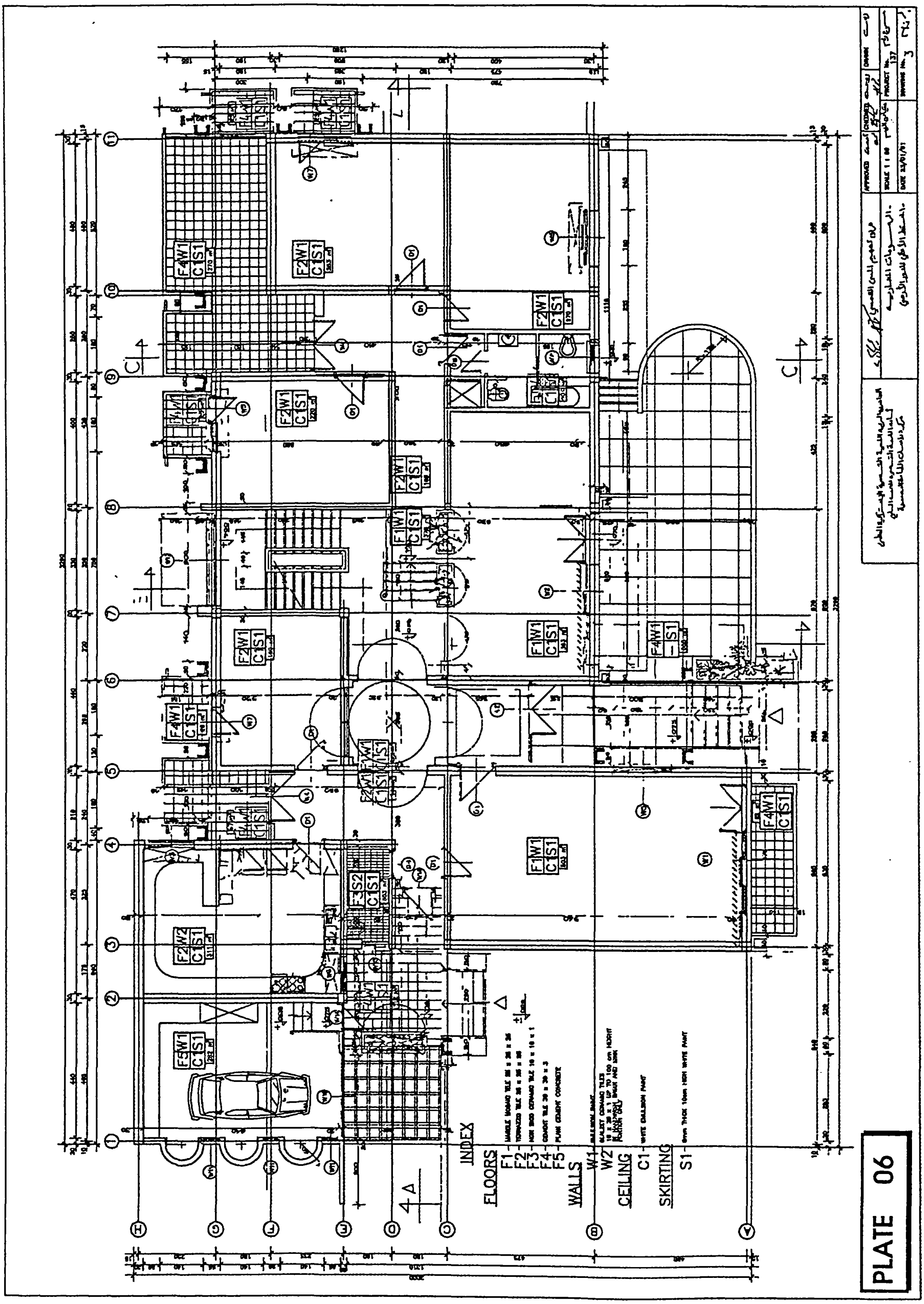
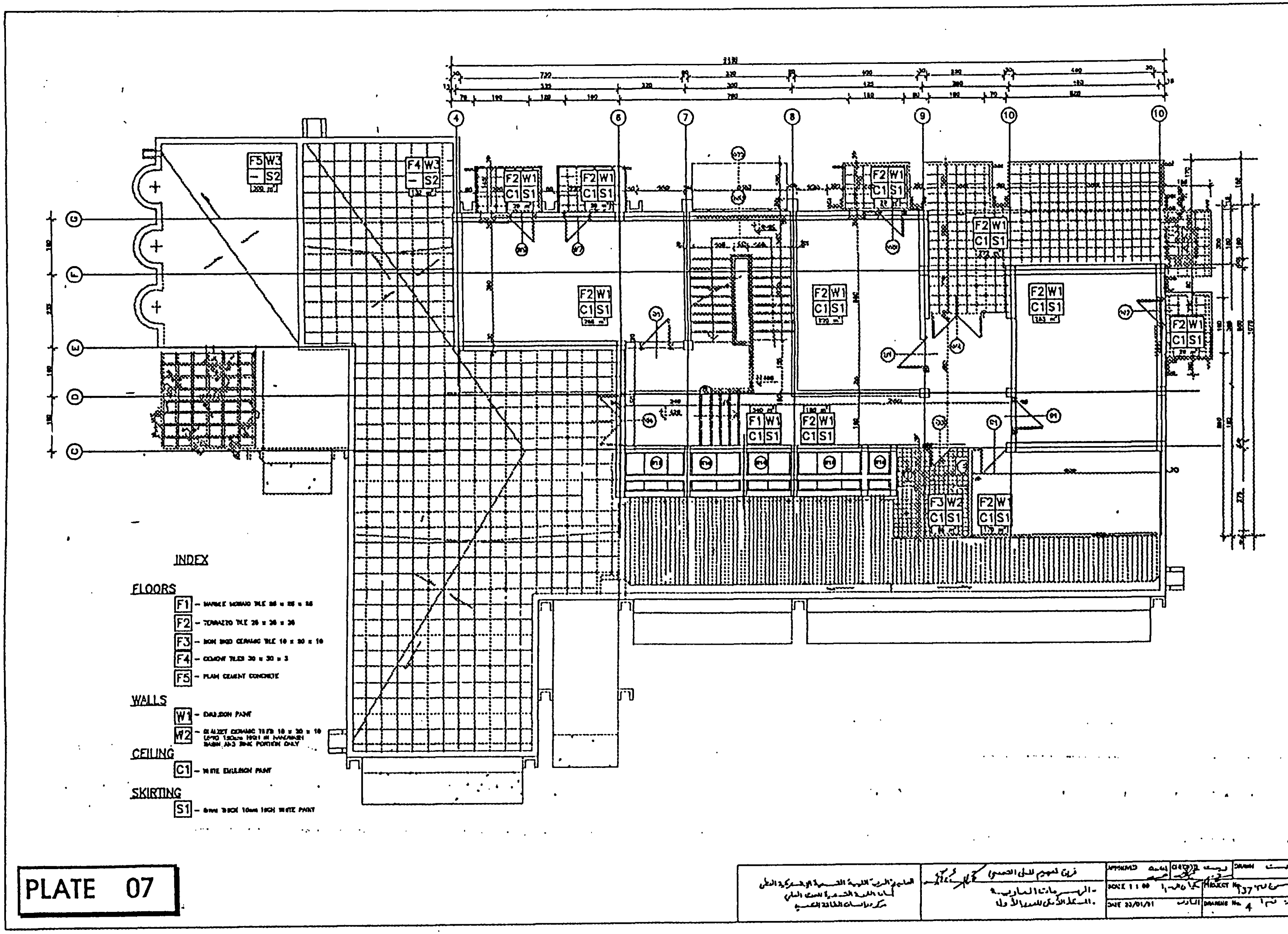
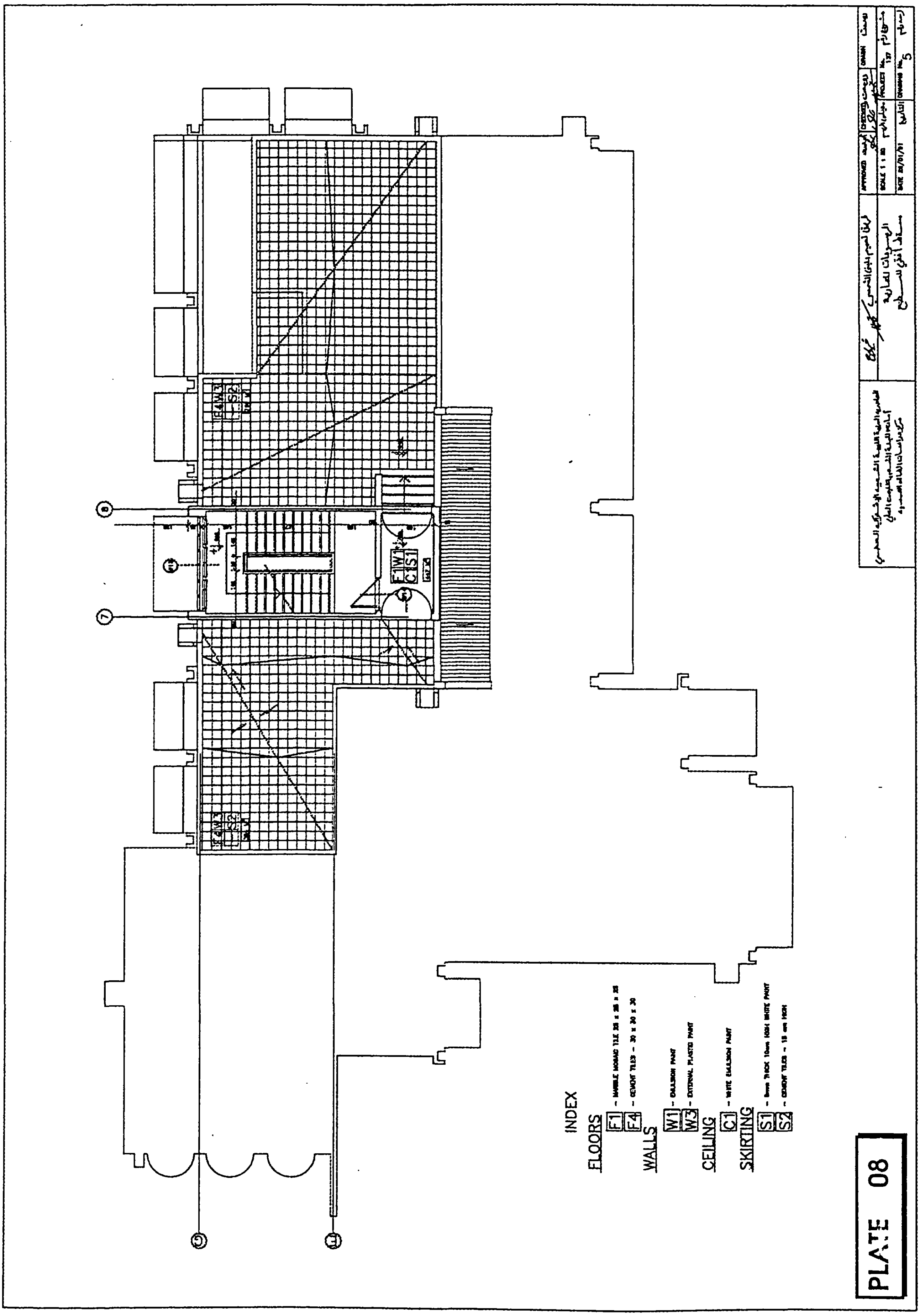
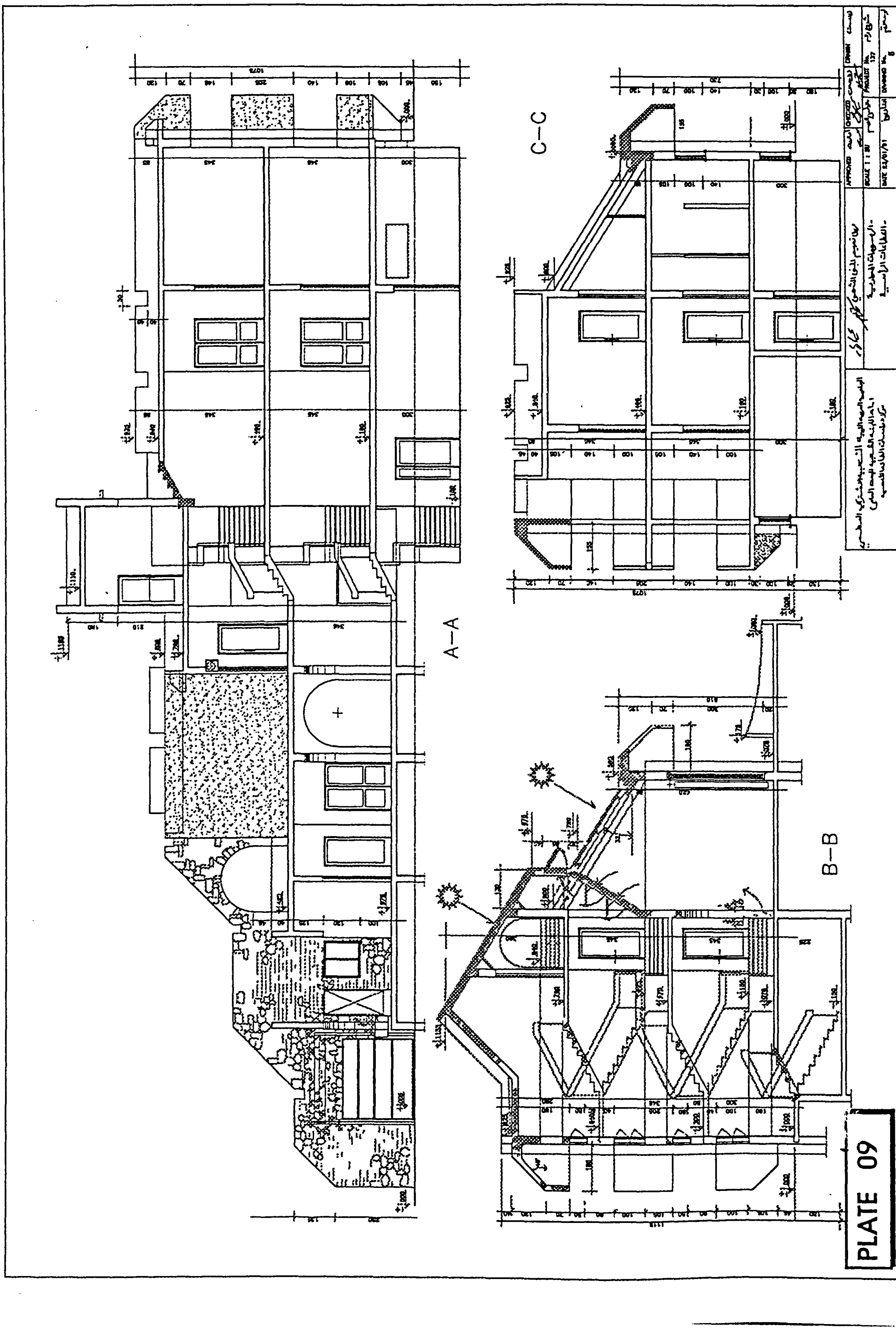


PLATE 06
INDEX
FLOORS
F1
F2
F3
F4
F5
WALLS
W1
W2
CEILING
C1
SKIRTING
S1


INDEX
FLOORS
F1
F2
F3
F4
F5
WALLS
W1
W2
CEILING
C1
SKIRTING
S1
PLATE 07


INDEX
FLOORS
F1
F4
WALLS
W1 - EMULSION PAINT
W3
CEILING
C1 - WHITE EMULSION PAINT
SKIRTING
S1
S2
PLATE 08


A—A
B—B
C—C
PLATE 09

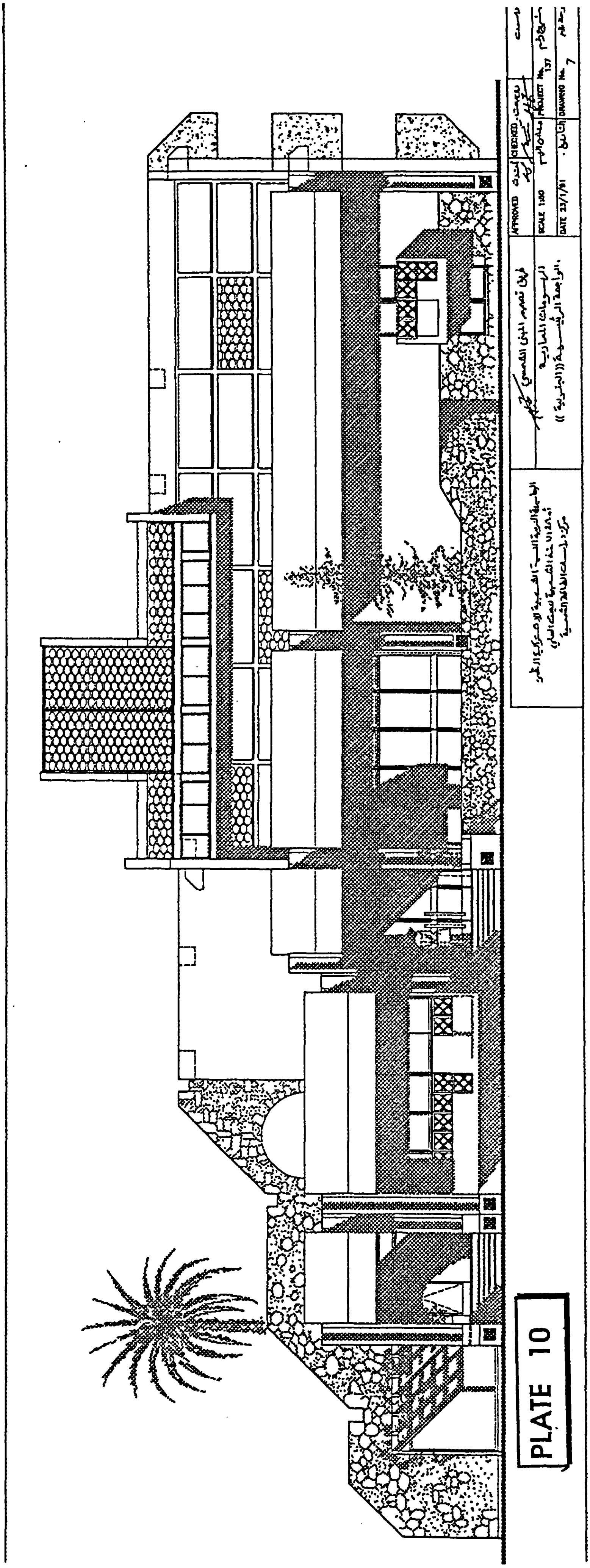


PLATE 10
APPROVED
CHECKED
SCALE 1:100
PROJECT No. 137
DATE 23/1/81
DRAWING No. 7

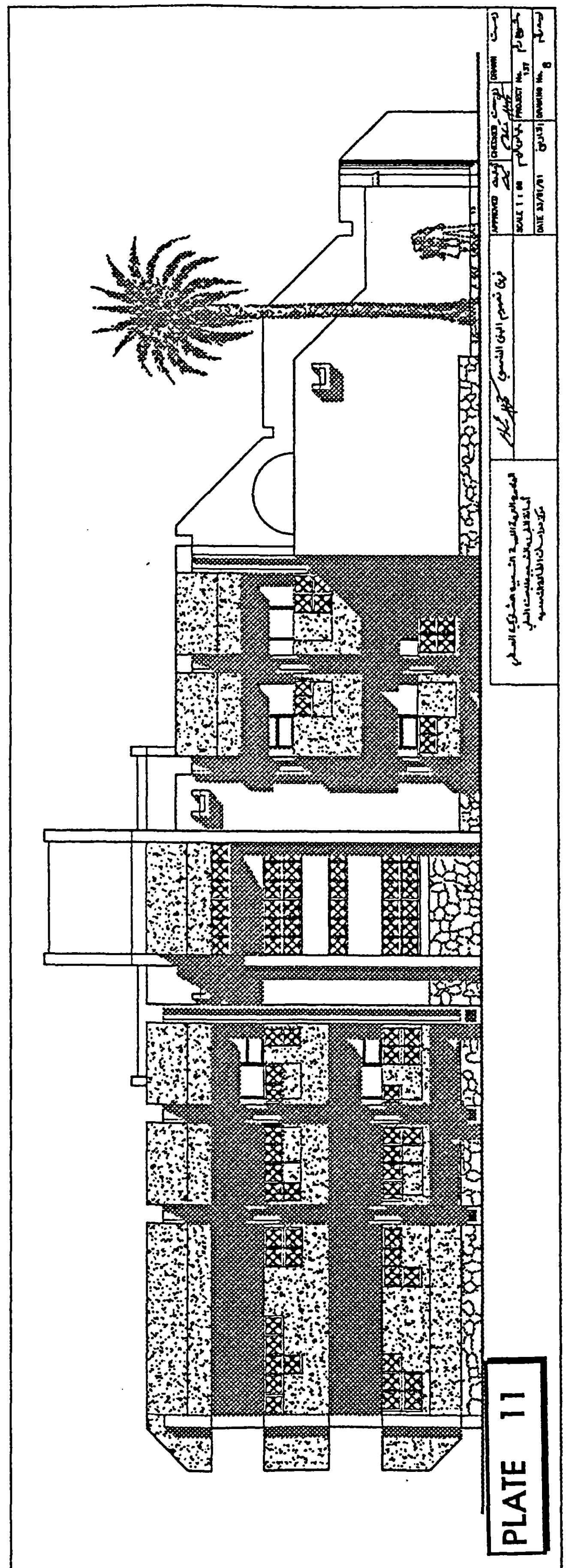


PLATE 11

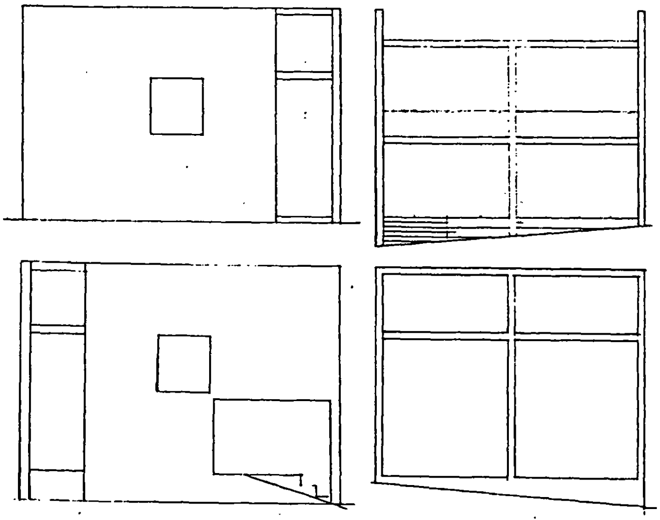
5.2 CASE STUDY: Energy Efficient House Design: Tripoli-LIBYA

5.2.1 The Design concept :

The design concept is based on the Pierre d'Avion design of the Mehr House in India which was designed in 1994. The solution as illustrated in d'Avions sketches of the house, plate(12, and 13) is simply an attempt to reflect architect's perception of the culture and landscape in India using simple form, and treatment of plain flat surfaces with carefully selected colours. In an interview with Pierre d'Avion, and to the question regarding his thought process in the development of the Mehr House, he states that "with the Indian house, I was much more confident about my relationship with client and the program much more straightforward, and it was a question of wanting to work a clear statement (...) I know it happens in the Indian scene in terms of making housing, they tend to get a very complicated little house, while I was trying to negotiate a different way of doing it and trying to lay that very clearly in presentation from the very outset.

There is not a great empathy in the Indian psyche to make very simple things and then fuss them up with decoration and colour.. and part of me is interested in that. That is one thing, the other thing is certain standards on space and so on and just fundamental things used to be there and still are there tend to be forgotten about (...). I was very keen to make clear things, so everything about the way that project was developed was to do with that-very obvious and straightforward" (1995)

As the study adapts a concept in the proposed model for the case study that is basically engendered by d'Avion,s solution, it is imperative to state briefly how the specific architectural solution that has been developed in the Mehr House works in terms of thermal performance. The open ground plan layout with the vertical circulation placed in the middle of the building, and generous height permits a satisfactory horizontal and vertical ventilation regime. These principals underlining this have already outlined in chapter 4, and Plates (12) and (13), indicate the detailed part played by the plan and sections.



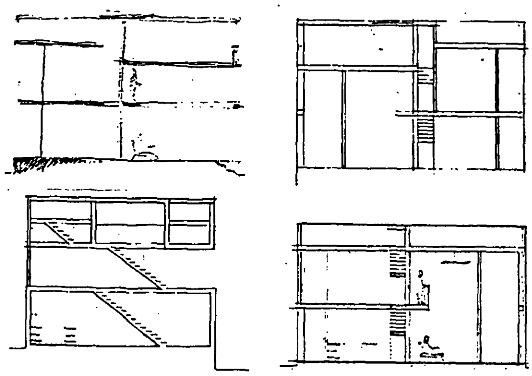
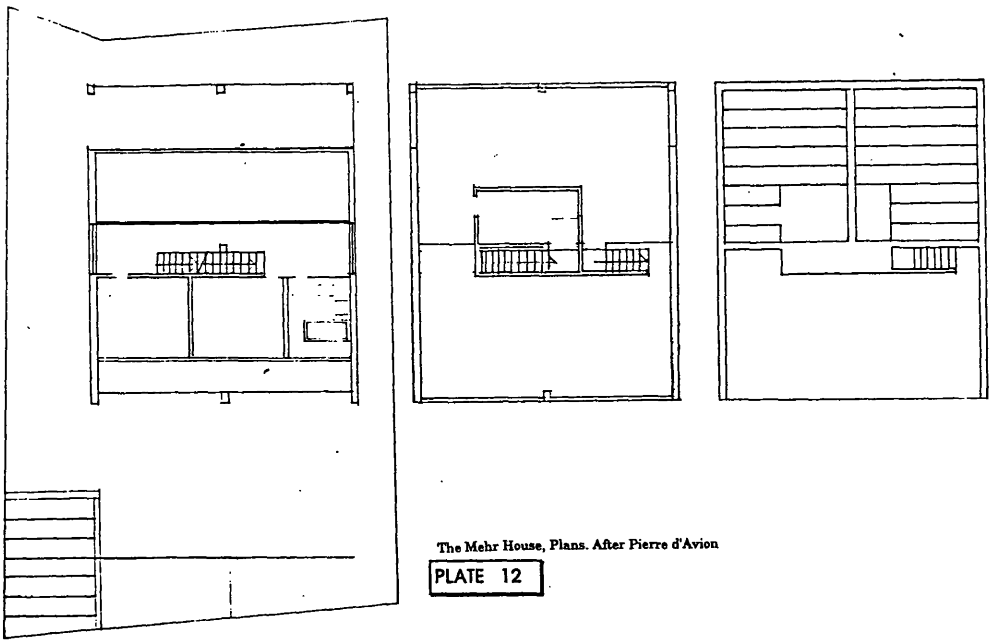


PLATE 13

The Mehr House, Sections and elevations. After Pierre d'Avion



The Mehr House, Plans. After Pierre d'Avion

PLATE 12

Plate (12), (13): P. d'Avion's Early Sketches of the Mehr House, (Pierre d'Avion, Pencil on Paper, 1994).

1- Design Consideration

Certain criteria have been acknowledged in order to adopt the d'Avion's solution as a suitable prototype for the environmental and human requirements in Libya. These are as follows:

a) Human Requirements:

The plan and section is based on particular spatial requirements and arrangements that the socio-economic context has determined that is .the average size of a typical Libyan family of 5 to 7 persons. The house consists of reception room, living room, kitchen and dining space, three bedrooms and a reading room, while the roof is treated as an additional open space for other activities.

Two important human needs may run against the grain of an open plan, which environmentally can be a successful solution. First culturally, privacy is a vital factor in the Libyan house. thus a division into three distinctive zones have been applied. The public zone is limited to the entrance space and reception which as a space has been separated physically and visually Plate (14,15). The semi-private zone includes the rest of the spaces on the ground floor, whereas the private spaces are located on the first floor. The only obstacle developed was how to permit cross ventilation between the public space and other spaces as well as the private spaces. A solution is to provide opening windows or vents at the top of the walls. dividing these spaces or above doors giving access to them. Unnecessary walls are also avoided on the ground floor and the section facilitates vertical movement of air, as well as significant stratification in the main day time living space.

Secondly, the occupation of spaces determined by traditional pattern of activity may run counter to the cyclical variation in temperature. Plates (17), (18), and (19).

In this case The occupancy of rooms -considering electric and mechanical equipment- as well as people has been classified as follows:

1) Living space: This includes the activities of living and reception rooms, the pattern of activity is illustrated in Figure (42,a).

2) Kitchen: the activity pattern is divided in terms of time into three periods during the day, as illustrated in Figure (42,b).
3) Bedrooms: The activity pattern is also divided into two periods: In addition to the night sleeping period, there is the midday siesta which characterises human behaviour in hot climates, Figure (42,c).
The positioning of the rooms vertically and horizontally together with construction and specification has to take account of there profiles in the most logical manner.

b) Environmental requirements:
Within this category, the effect of climate on the design is examined. As a result three basic passive principles have been suggested: The building form and orientation, building's envelope and material, and shading strategy,

1)Building's form and orientation, the building's form is nearly a cubic shape. This is to reduce the exposed surfaces, and have surface to volume ratio, and by adopting a compact two story form the area is minimised and the day-rooms are protected by sleeping rooms. Height is also useful to exploit thermal buoyancy Plate (19).

A 1.5 story high living room on the south side gives scope for warm air stratification close to the ceiling; and at the same time generates a split level section to facilitate stack induced air flow through a central stairwell; but without precluding cross ventilation from south to north or vice versa across the two room plan depth, Provided the two south facing bed rooms and the living room can be adequately shaded in summer the apparent imbalance between north and south is not significant; and in winter warm air can circulate up to the two north facing bedrooms from the living room, the main beneficiary of solar gain.

Again in summer desirable north breezes can be captured by north facing windows move across circulation space and into south facing rooms. In plate, ESP visualisation illustrates the effect of the summer and winter sun on the building (note the effect of shading devices).

2) Building's envelope and materials: The analysis in chapter 4 make a strong case for insulated construction, both to reduce heat loss in winter and slow down and damp down heat gain in summer. It was hence decided that the most appropriates specification for the walls was the cavity hollow concrete block with polyurethane as insulation material; and for the roof the hollow brick with concrete ribs and polyurethane as insulation. The roof acknowledges the role of the above bedrooms flow in protecting the day spaces on the ground floor.

3) Shading strategy: Again further to the appraisal in chapter 4, the proposals in this respect are as follow:
a- Glazing type and shutters: Double glazed windows are used in order to reduce the amount of heat flow. This is also augmented by providing shutters.

b- The south overhang provides fixed structural shading to the tallest main space in the house. This is valuable in that the most used space with most fenestration is not too reliant on shutter for summer control and can enjoy adequate daylight and aspect, even in hot weather. Plates (28) and (29), shows the effect on the ground floor windows, while a fixed louvered shading device has been used in the first floor windows. The overhang also gives architectural strength and clarity to the south facade, allowing the principal space to be need as such, as well as delineating an outdoor terrace. Plates (21) and (22).

c- Use of vegetation is one of the passive cooling techniques in the proposed model. As it is discussed in chapter 2 and 4, vegetation is applied in three parts of the building: The roof with a vine pergola, West elevation with the green wall, and on the ground as a soil modifier to enhance the performance of the underground cooling system Plates (16) and (23). The green wall or screen, as well as shielding the west facade, defines a second outdoor room (the first being the terrace below the overhang). This may be used for a variety of utilitarian or leisure activities- e.g. car-pool, clothes drying, shaded outdoor sitting etc. Plate (20).

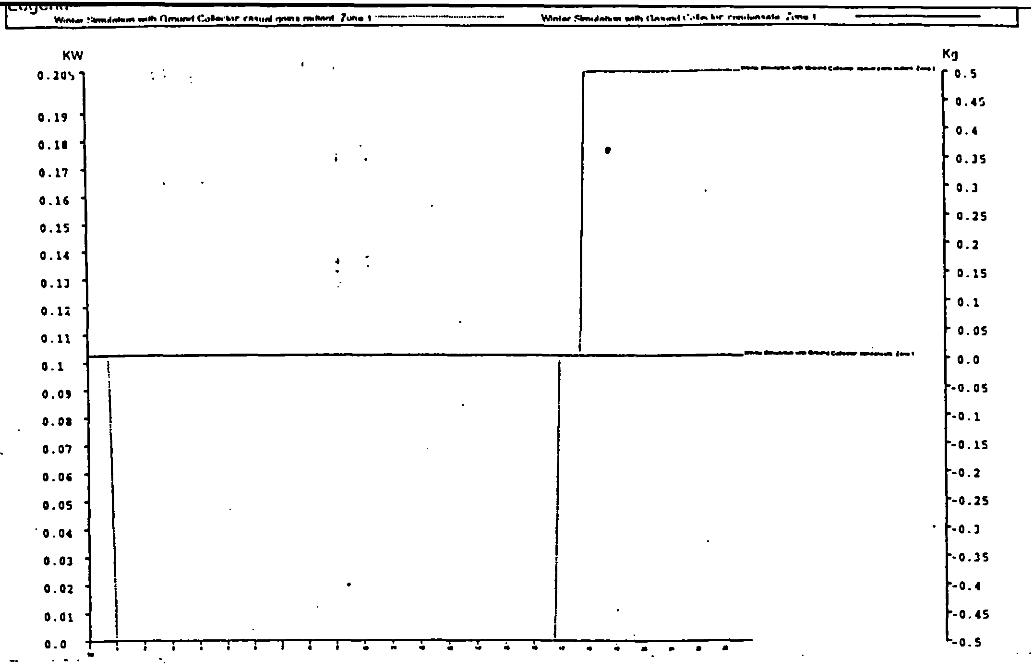


Figure (42a)

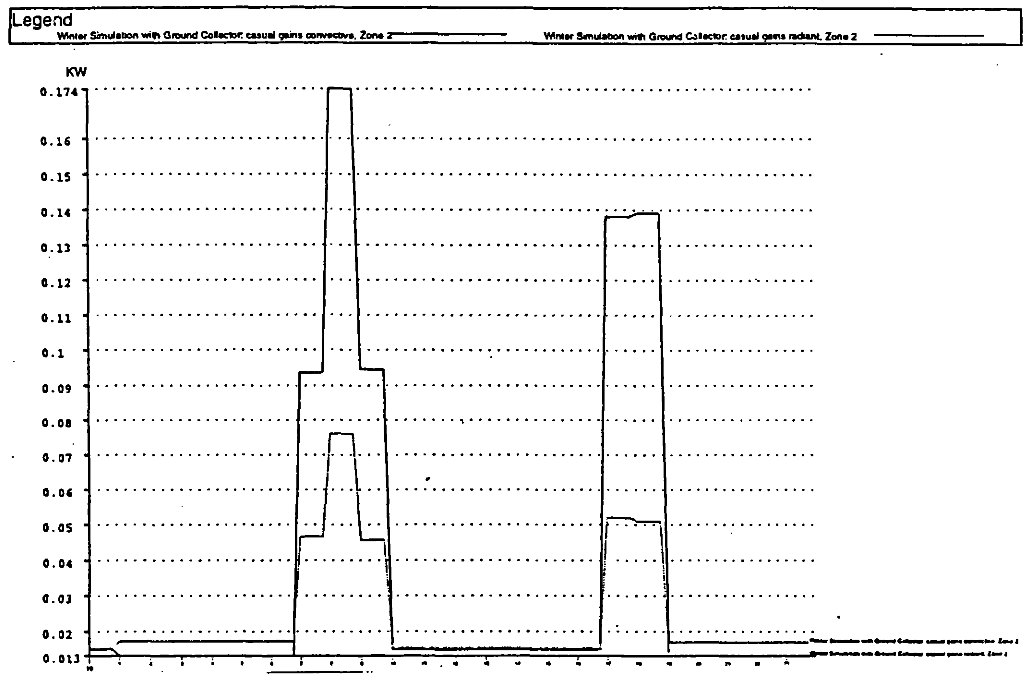


Figure (42b)

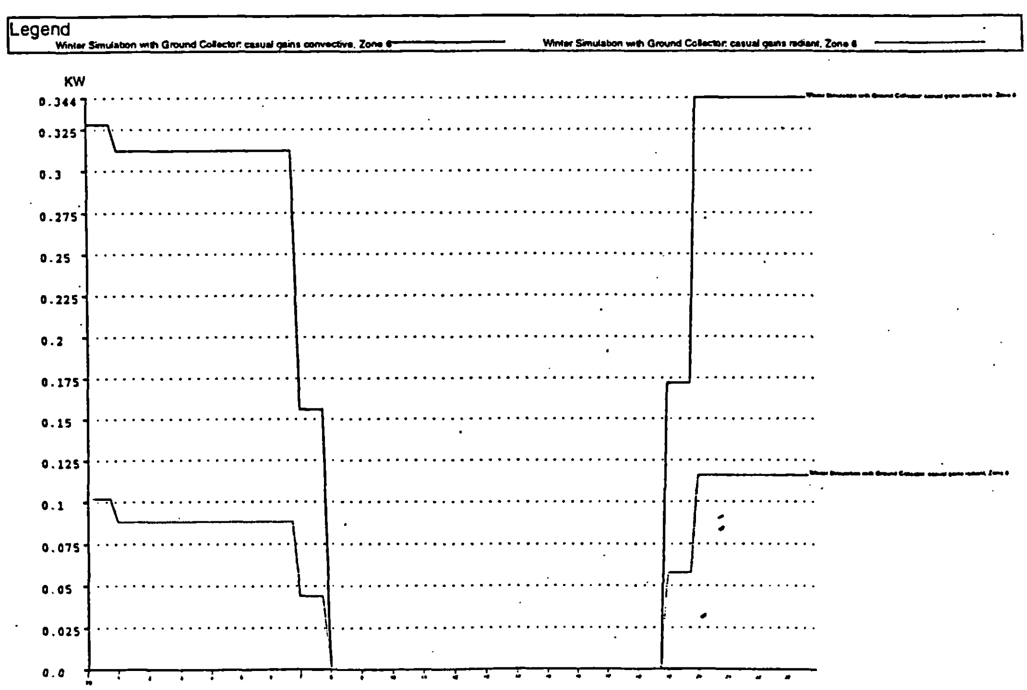


Figure (42c)

2) CAD application in the spatial visualisation of the proposed model

Other computer applications: Although architects are using computers mainly as a draughting tool, it can be argued that there may offer important design support in terms of visualisation. This enables rapid exploration of the potentialities and limitations within the context of proposed architectural compositions.

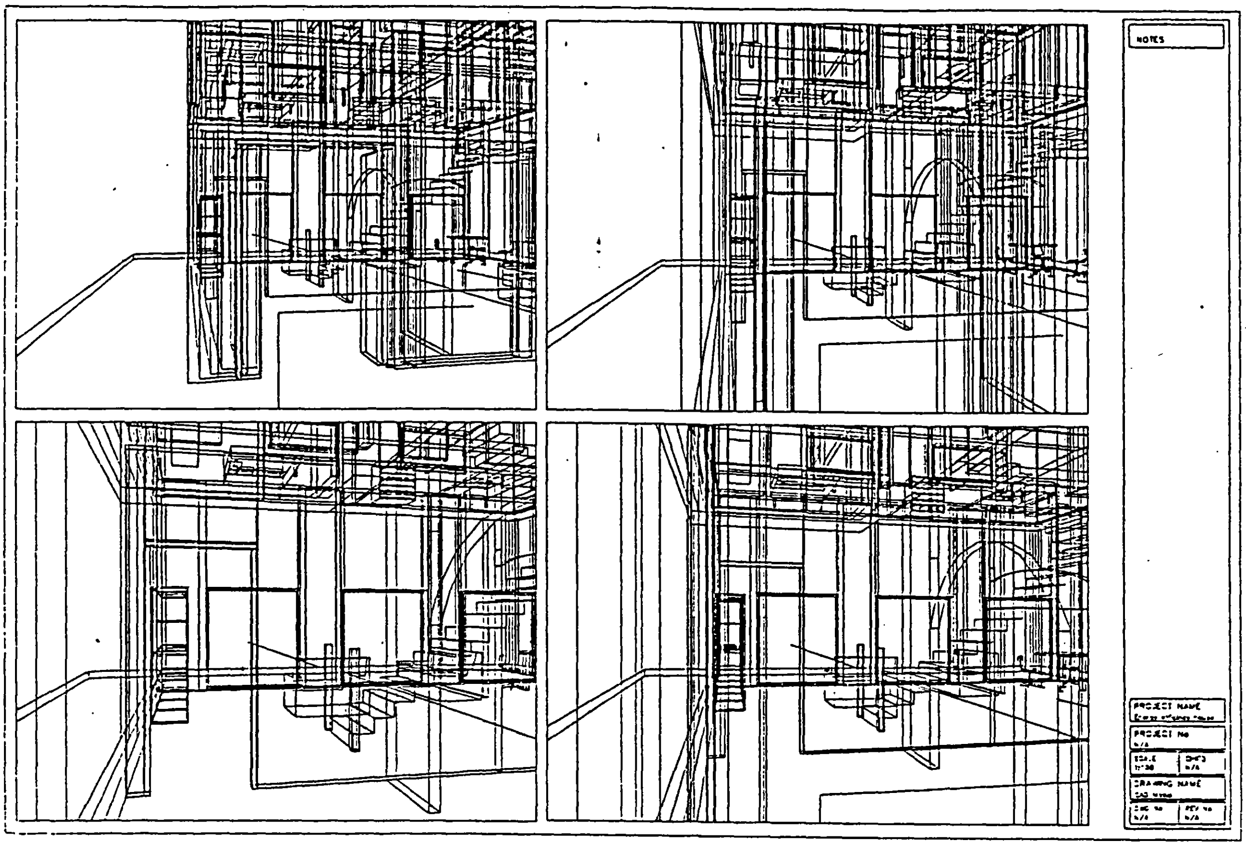
This study has utilised CAD application in such respect of manipulation as a skilful operation; and artful activity in the design process, that computers offer, together with the three-dimensional model. Through the utilisation of the manipulative capabilities of the computer, AutoCad R12 AEC as a software provides the possibility of 3-D exploration where specific graphical changes can be easily be executed.

The four basic manipulative operations of most computer software are: 'translation', 'rotation', 'reflection', and 'inversion'. In this study, the use was a means of directed experimentation in the design development, used to examine the spatial arrangement of the proposed model constructed in the computer.

A 'Walkthrough' command allows the designer to construct a visual impression by creating a series of images that simulate the views a person would see walking through the building.

A series of paths is created through the building for the purpose of spatial visualisation, illustrated in appendix (C). For example, in investigating the privacy factor, a series of images (13a) was developed along a path in the plan to represent the movement of a person from the main entrance to the guest room. Thus through the perspectives, the assurance of privacy is examined visually.

Moreover, generating another series of images (13b) from the living room to the guest room, shows that the internal window required more privacy in terms of visual contact from a person moving upstairs or downstairs. The solution is a 'mashrabia' which allows air movement but at the same time provides more privacy.



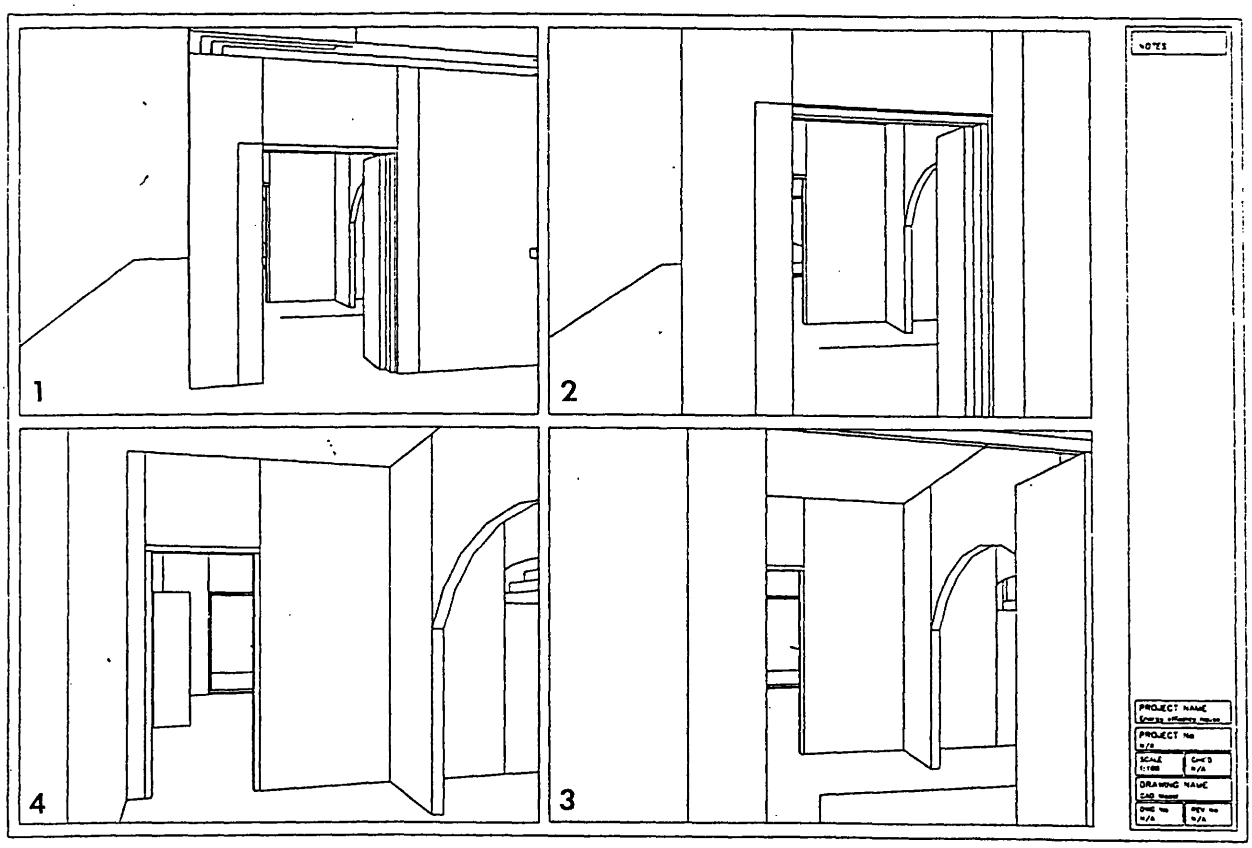
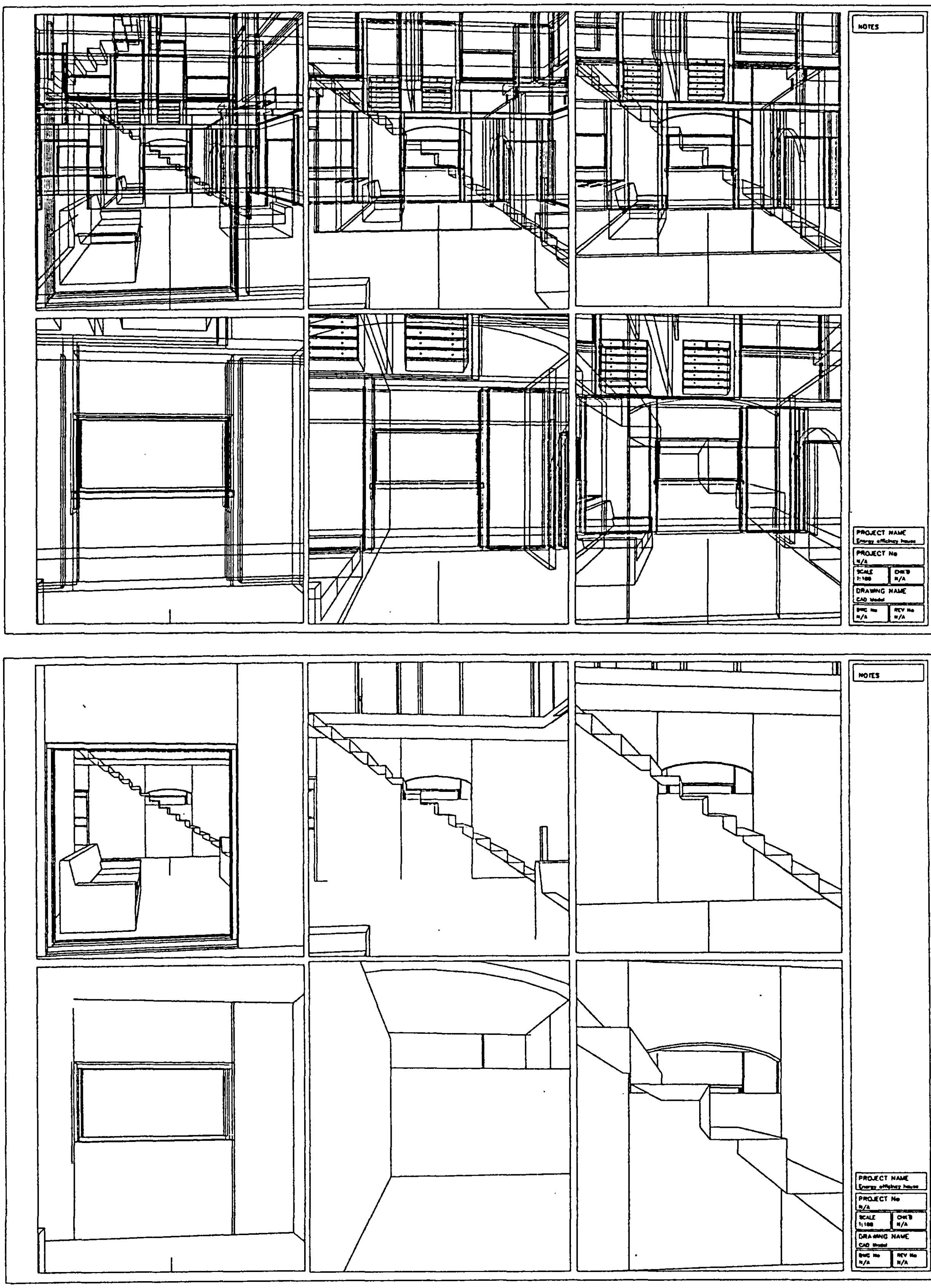


Plate (13a)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Energy efficiency house
PROJECT No
N/A
SCALE
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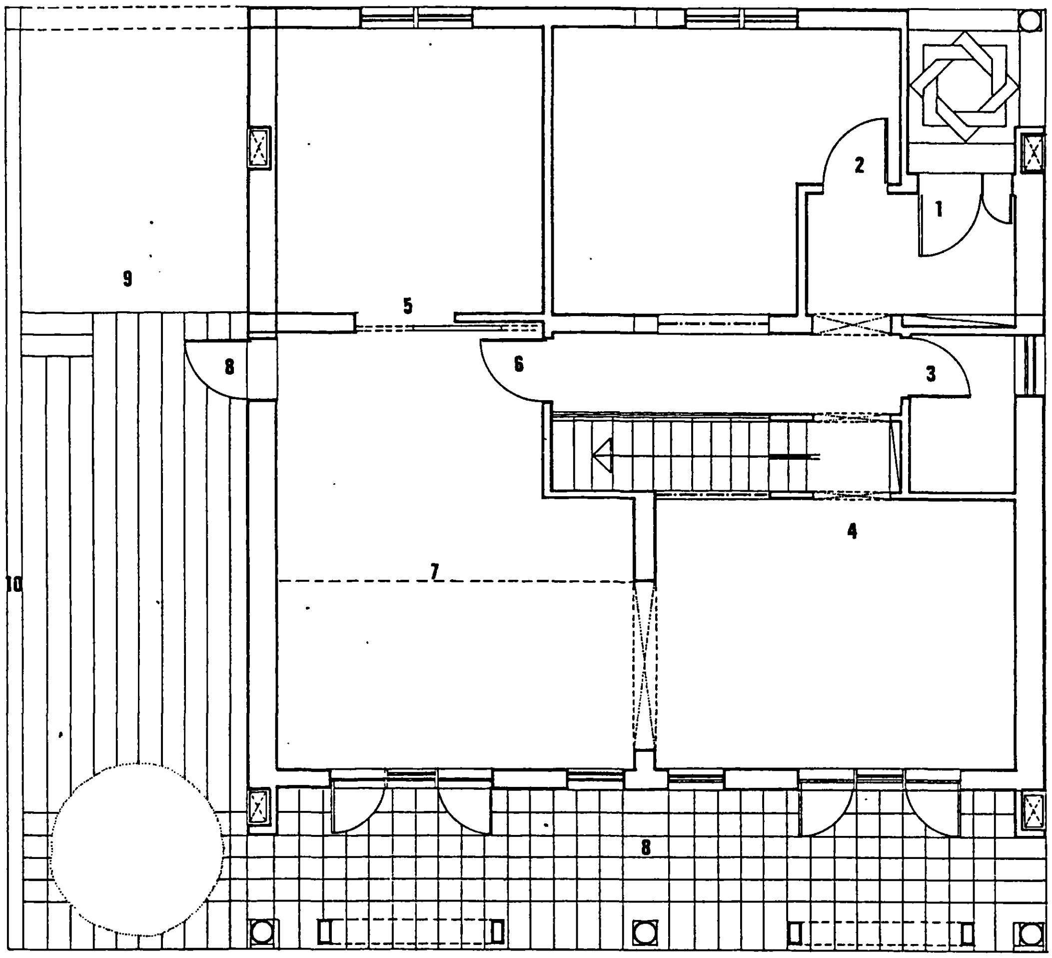
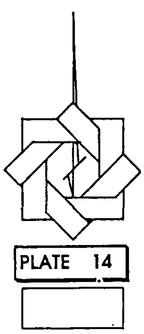
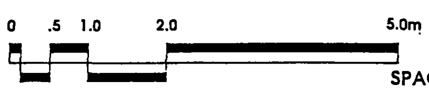
CHK'D
N/A
DRAWING NAME
CAD Model
DWG No
N/A
REV No
N/A

Plate (13b)

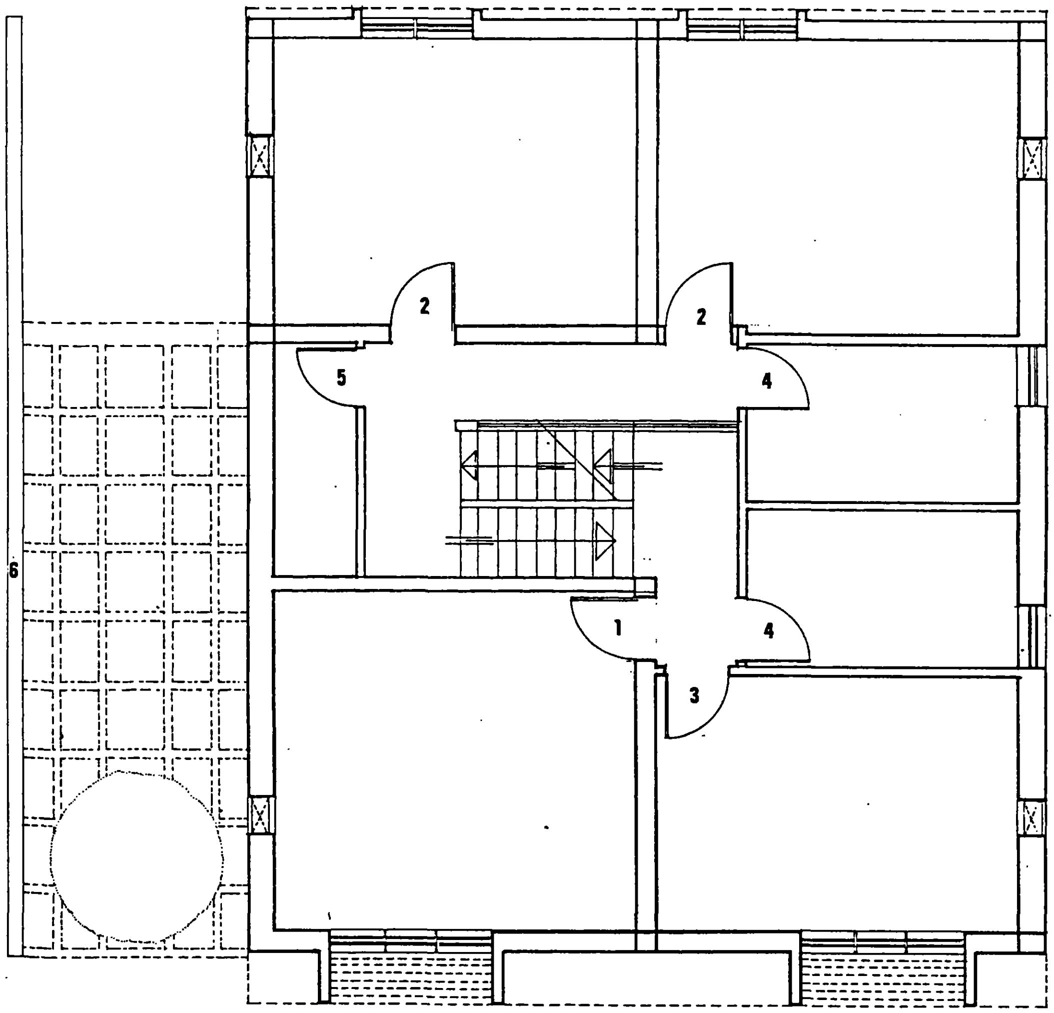






GROUND FLOOR PLAN
CLIMATE - CONSCIOUS PROTOTYPE

SPACES:
1- Entrance.
2- Visitor Reception.
3- Sanitary.
4- Living.
9- Car Parking.
5- Kitchen.
6- Service.
7- Dining.
8- Terrace & Garden.
10- Green Wall



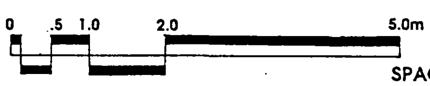
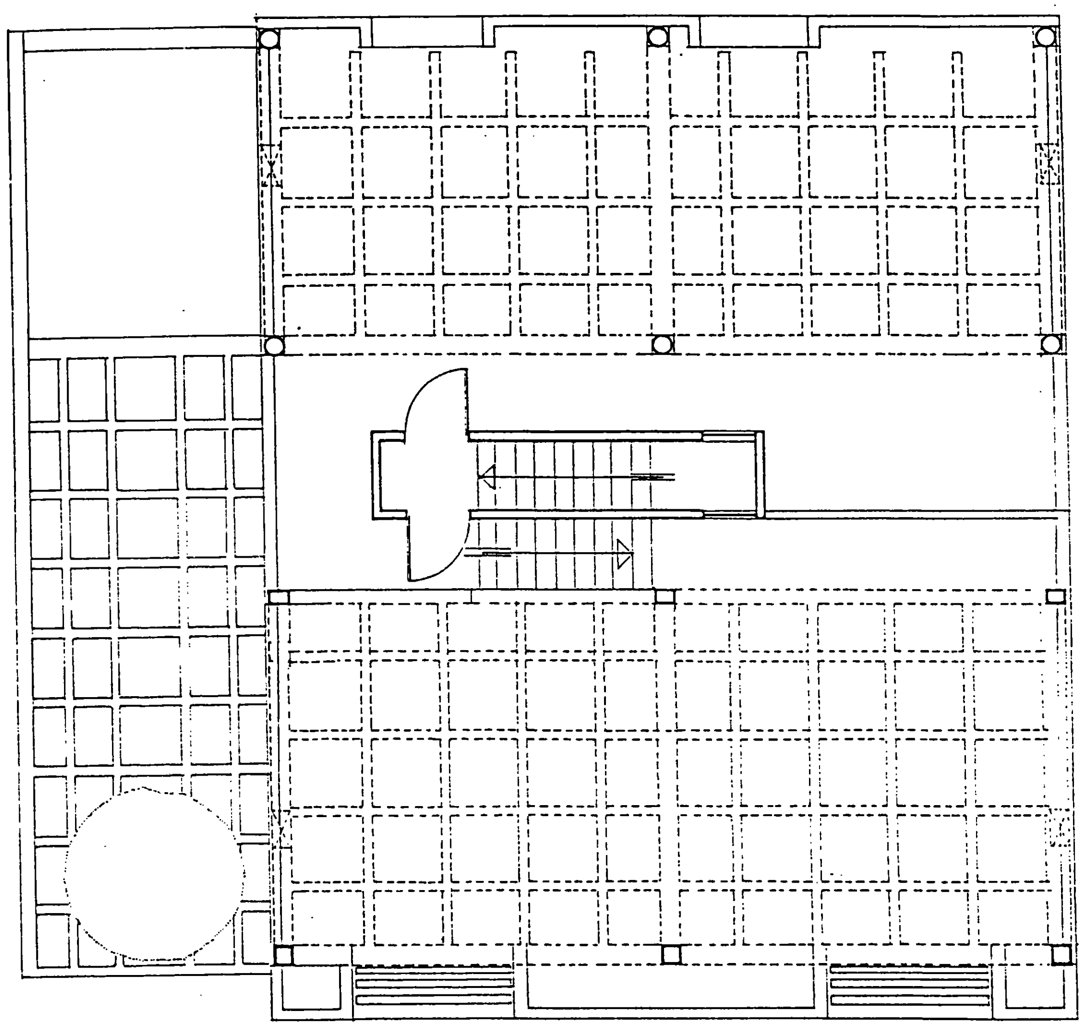


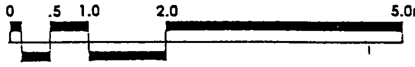
PLATE 15

FIRST FLOOR PLAN
CLIMATE - CONSCIOUS PROTOTYPE

SPACES:

1- Master Bedroom.
2- Bedroom.
5- Storage.
3- Reading.
4- Sanitary.
6- Green Wall.





SPACES:

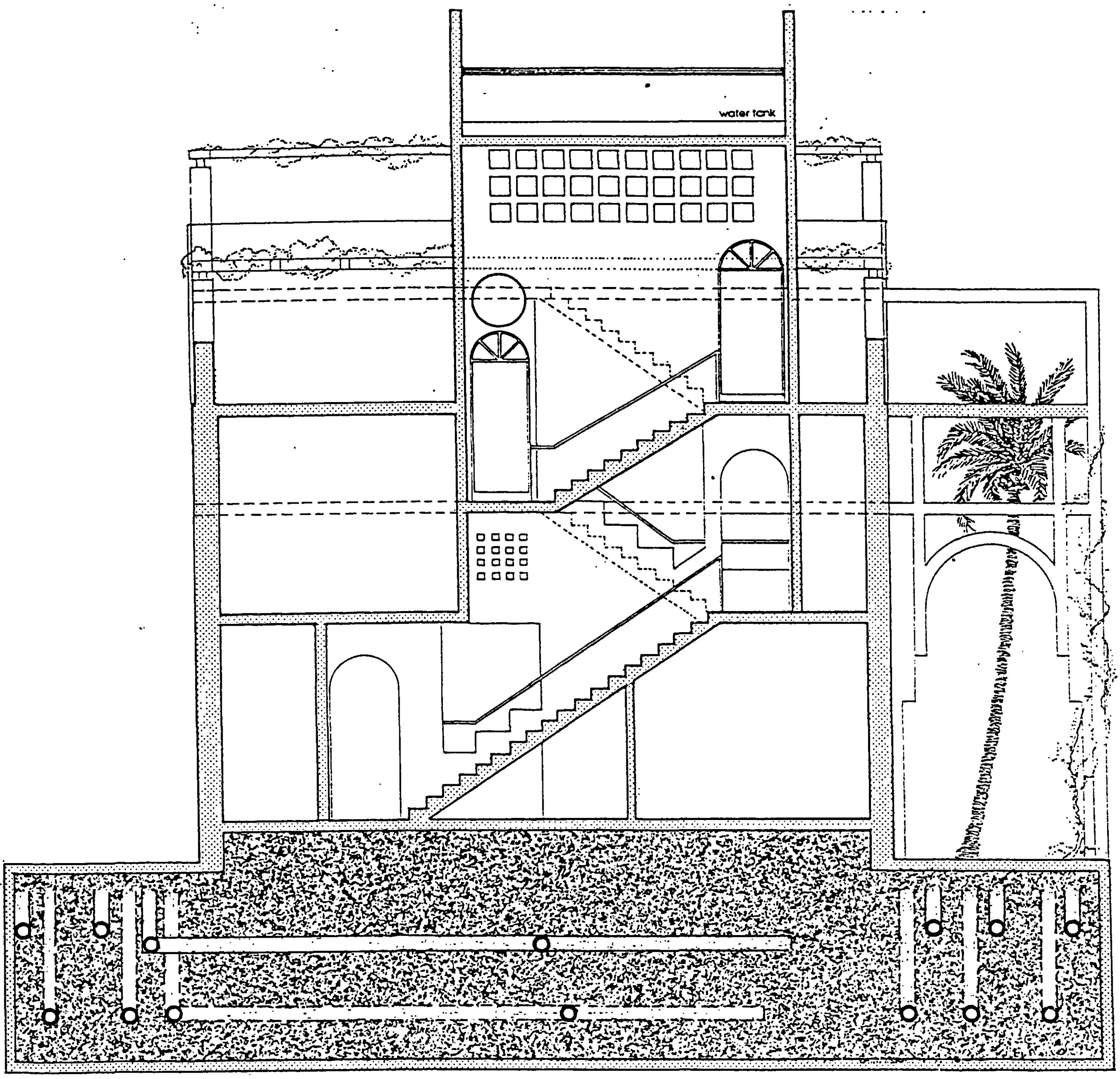
1- Roof Garden with vine

2- Water tank.

PLATE 16

ROOF PLAN

CLIMATE - CONSCIOUS PROTOTYPE



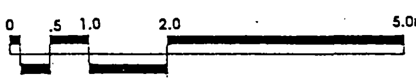
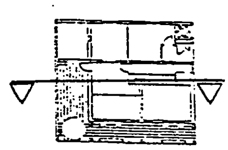
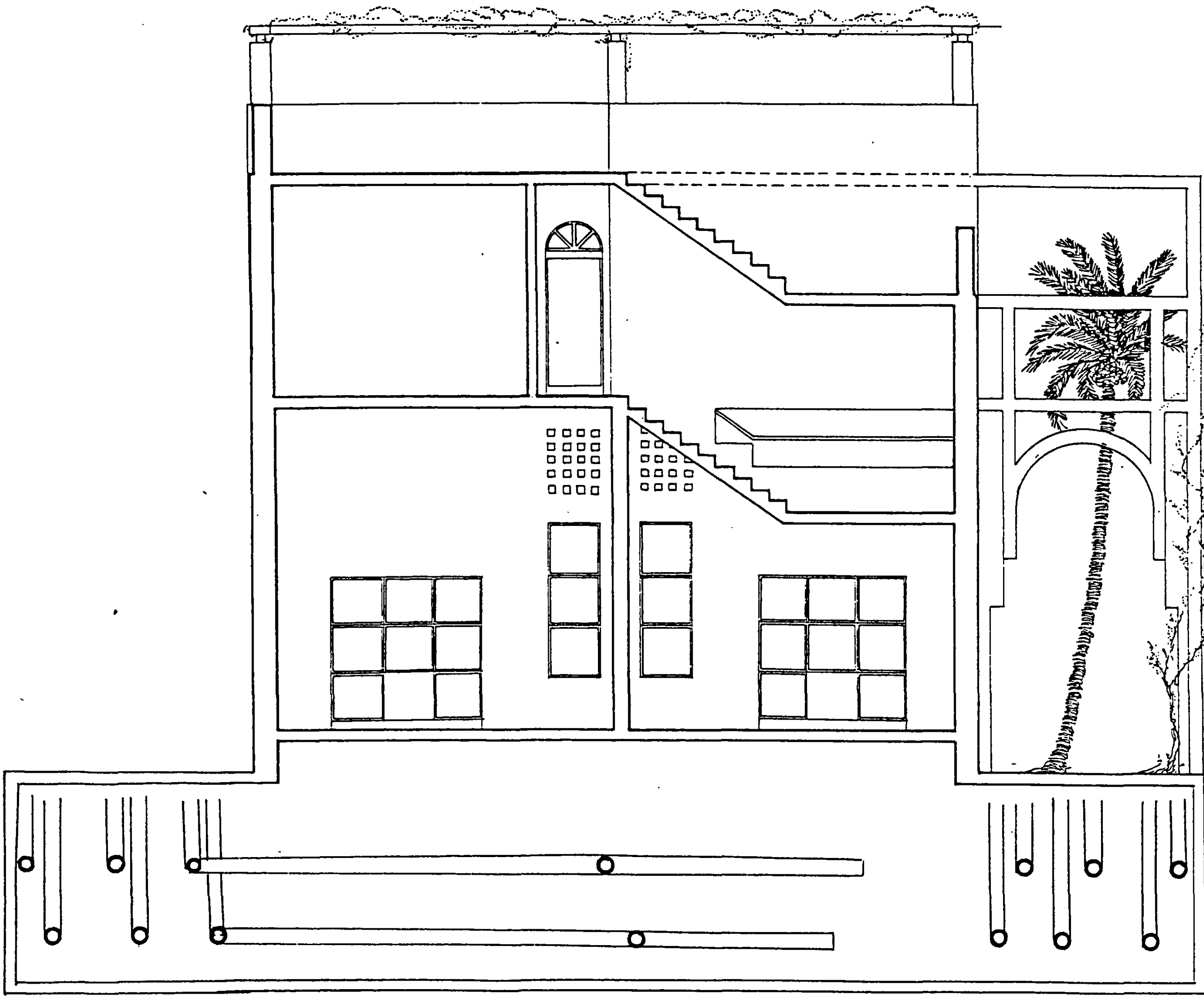
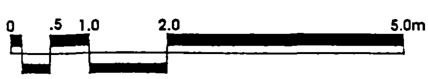


PLATE 17

SECTION A - A
CLIMATE - CONSCIOUS PROTOTYPE







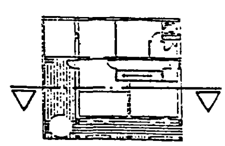
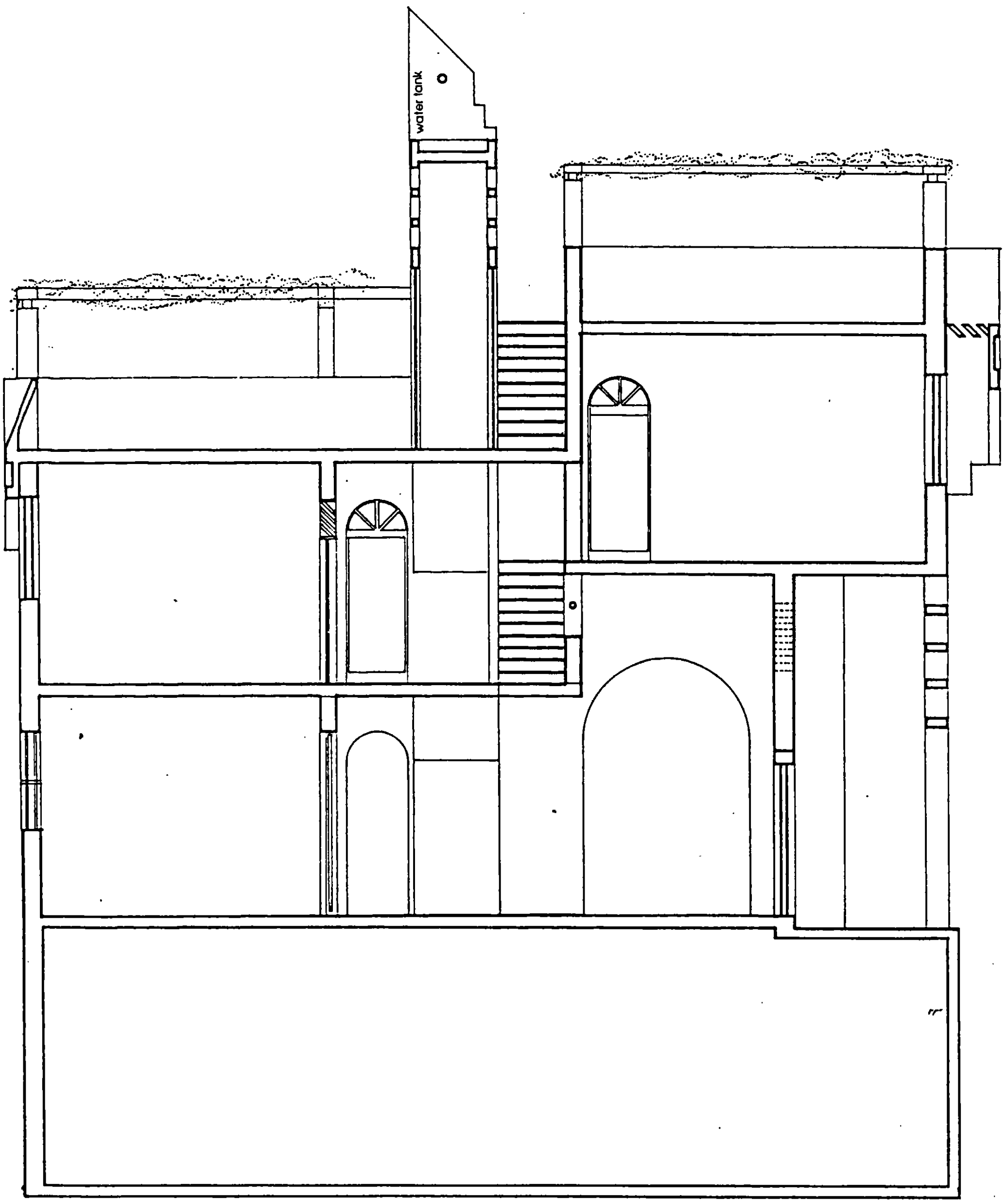


PLATE 18

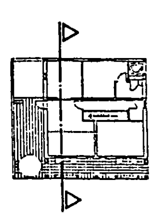
SECTION B - B
CLIMATE - CONSCIOUS PROTOTYPE



0 .5 1.0 2.0 5.0m

PLATE 19

SECTION C - C
CLIMATE - CONSCIOUS PROTOTYPE



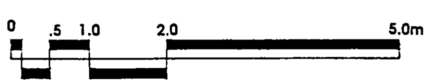


PLATE 20

NORTH ELEVATION
CLIMATE - CONSCIOUS PROTOTYPE

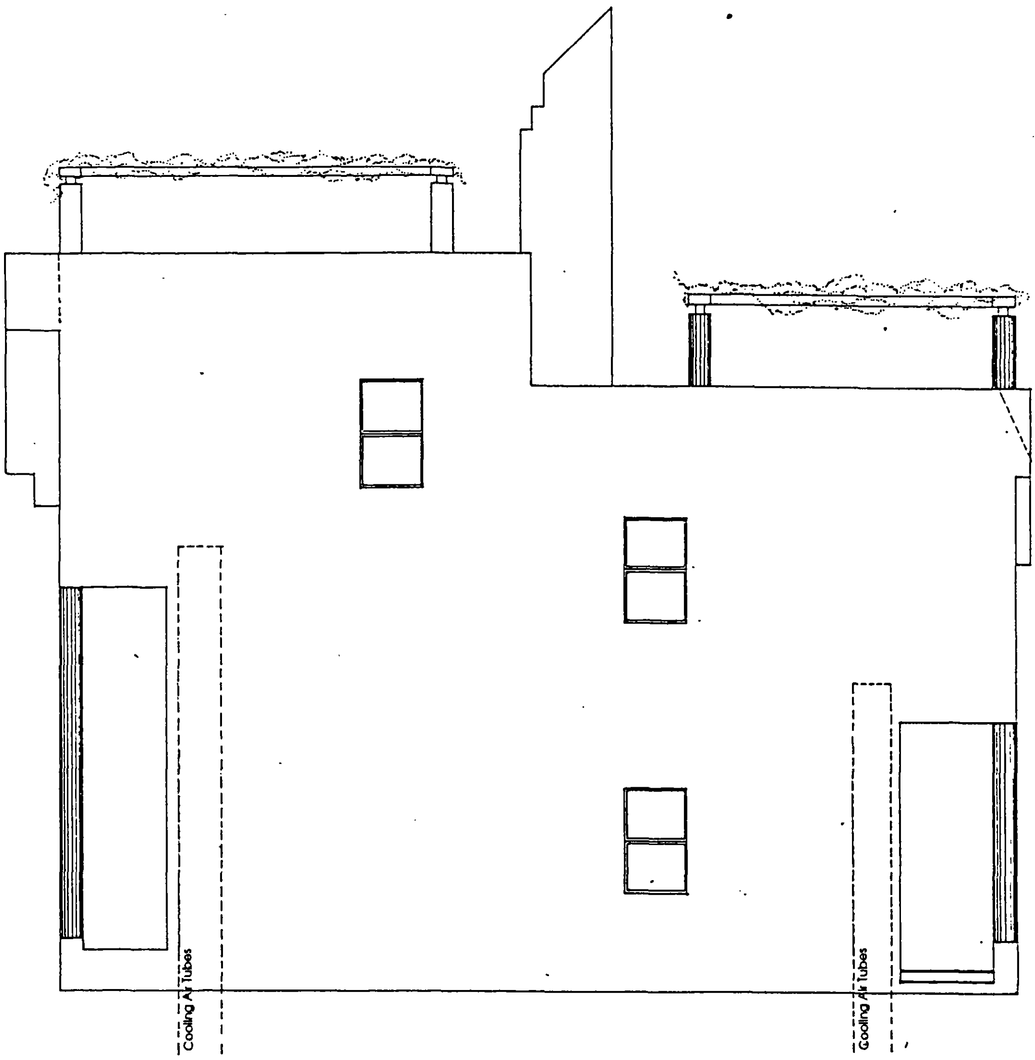


PLATE 21

0 .5 1.0 2.0 5.0m

EAST ELEVATION
CLIMATE - CONSCIOUS PROTOTYPE

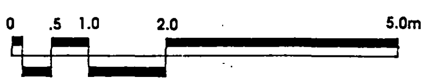
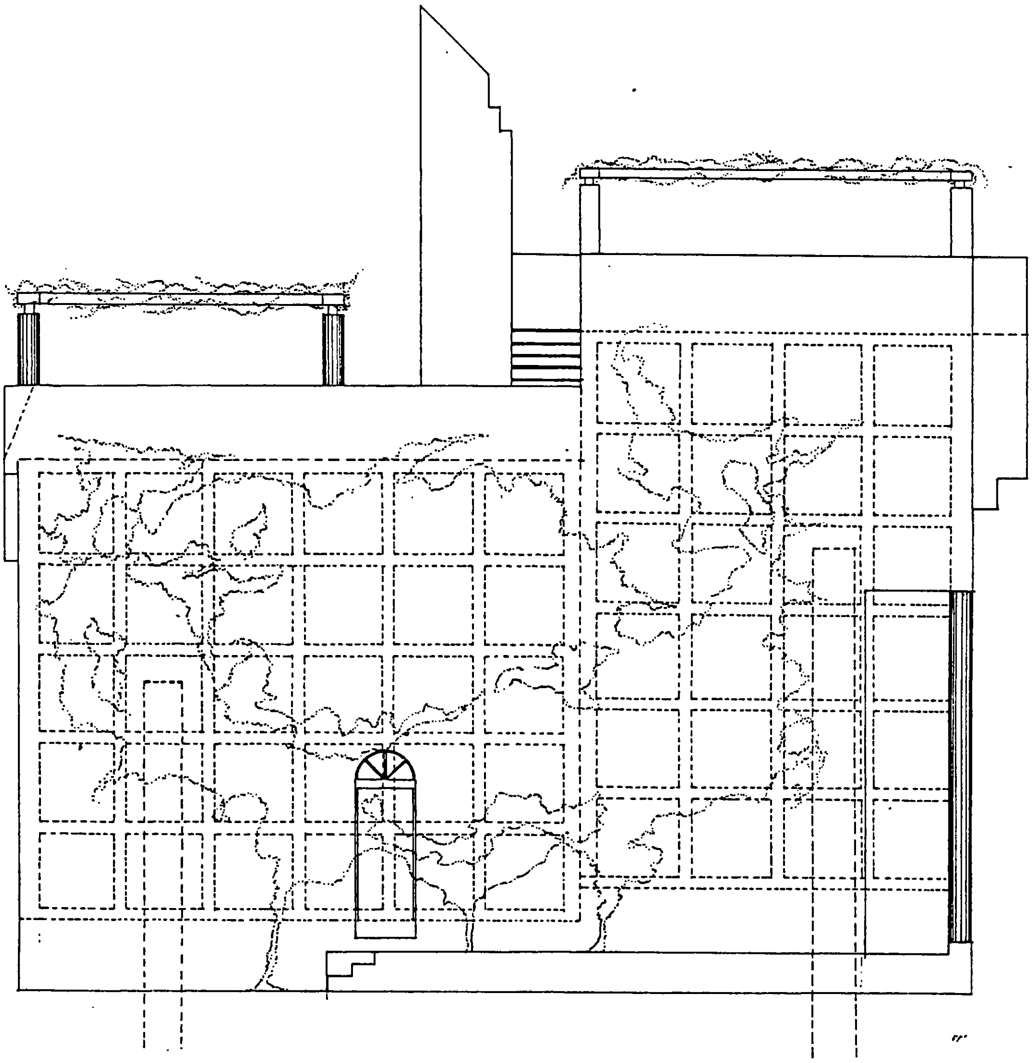


PLATE 22

SOUTH ELEVATION
CLIMATE - CONSCIOUS PROTOTYPE



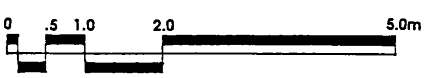


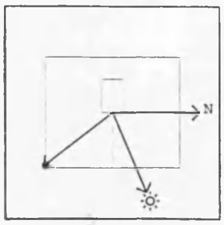
PLATE 23

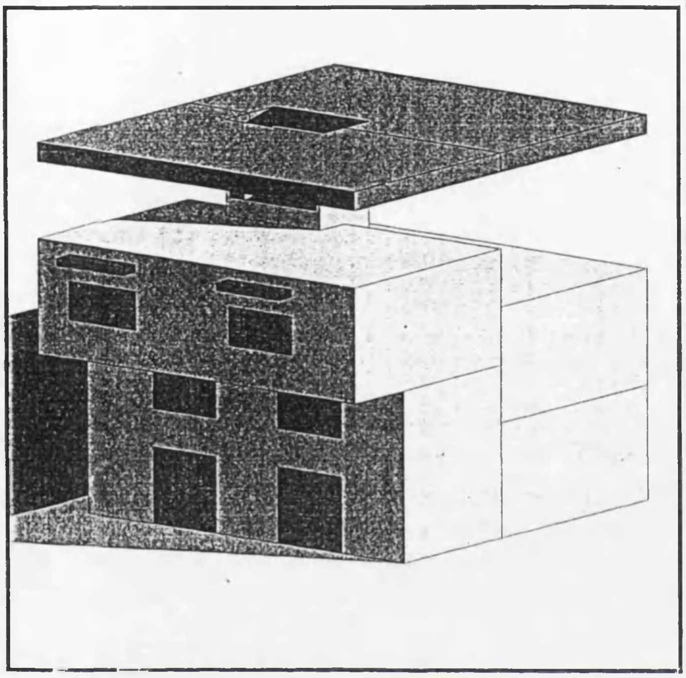
WEST ELEVATION

CLIMATE-CONSCIOUS PROTOTYPE

Proposed model, Tripoli.

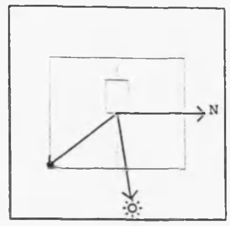
16 Jul 5:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 67.30 alt = 4.23
Eye : azi(y) = 232.00 alt = 12.00

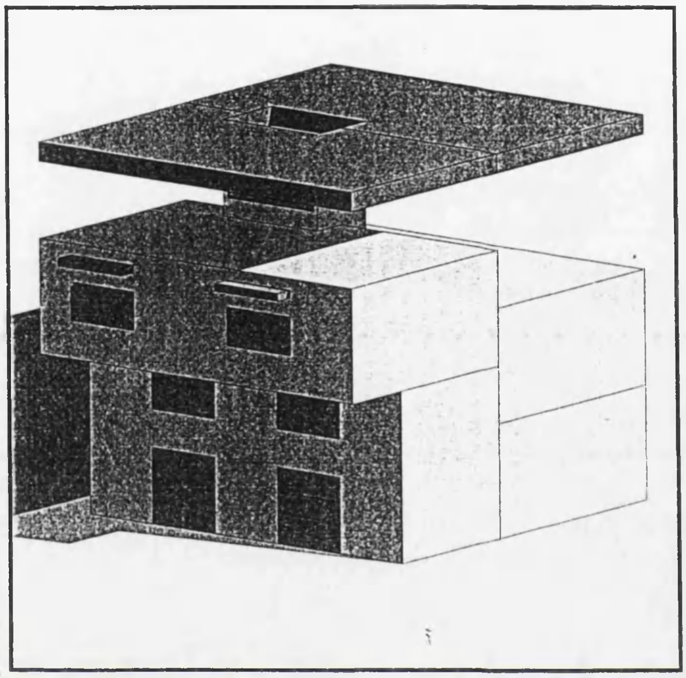




Proposed model, Tripoli.

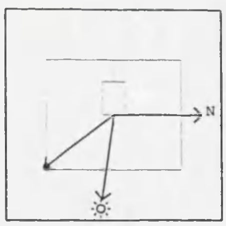
16 Jul 7:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 81.67 alt = 28.56
Eye : azi(y) = 232.00 alt = 12.00

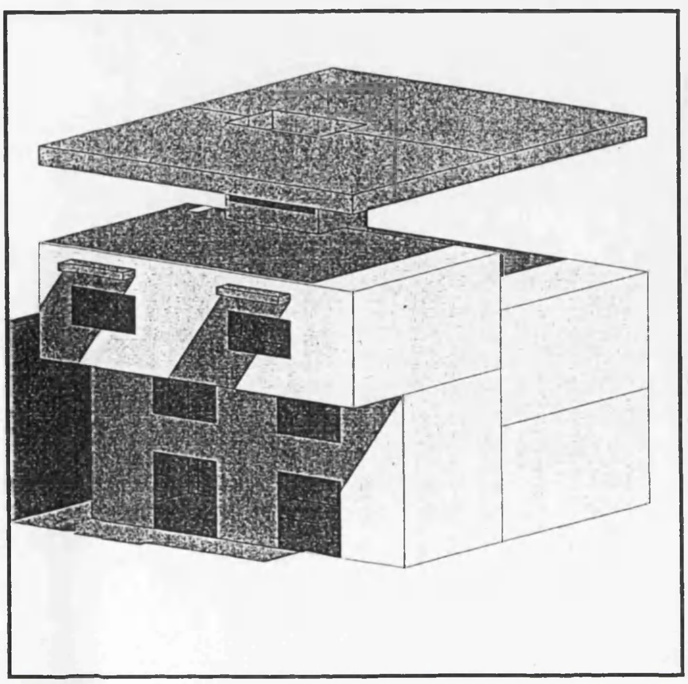




Proposed model, Tripoli.

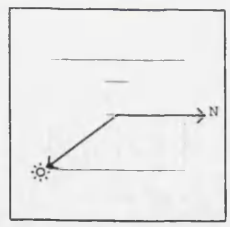
16 Jul 9:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 97.99 alt = 53.78
Eye : azi(y) = 232.00 alt = 12.00





Proposed model, Tripoli.

16 Jul 11:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 142.33 alt = 76.32
Eye : azi(y) = 232.00 alt = 12.00



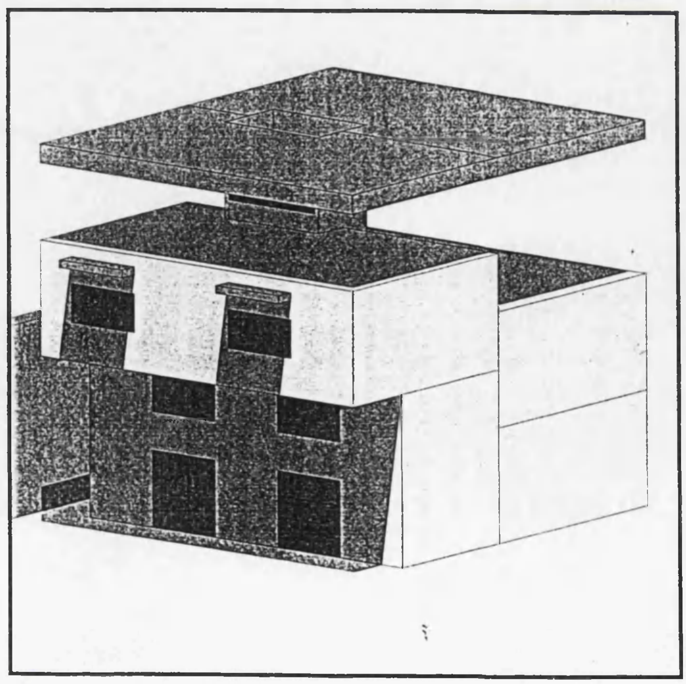
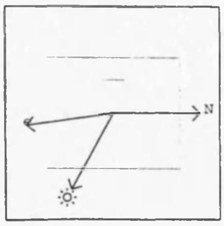
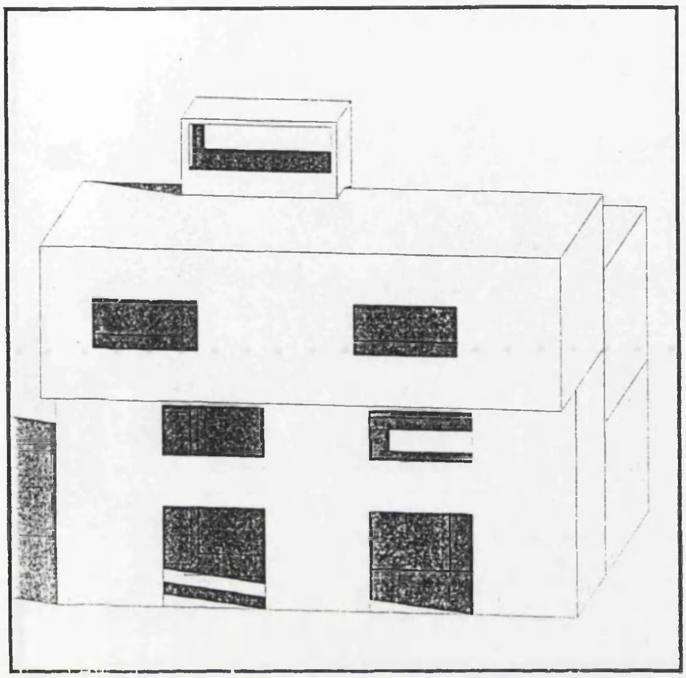


Plate (24 a)

Proposed model, Tripoli.

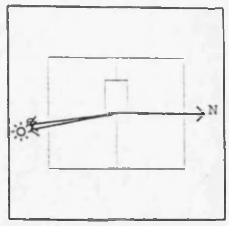
16 Jan 7:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 118.50 alt = 4.41
Eye : azi(y) = 262.00 alt = 12.00

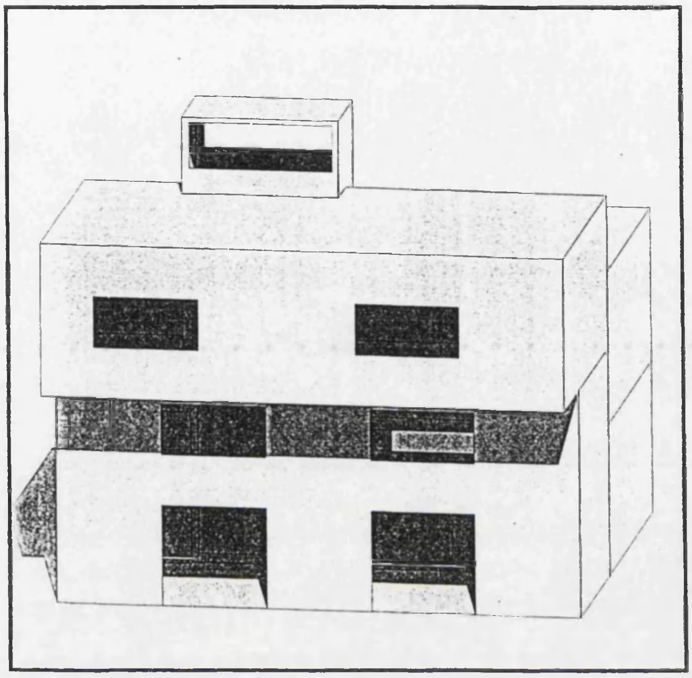




Proposed model, Tripoli.

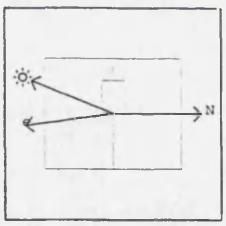
16 Jan 11:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 168.62 alt = 35.57
Eye : azi(y) = 262.00 alt = 12.00

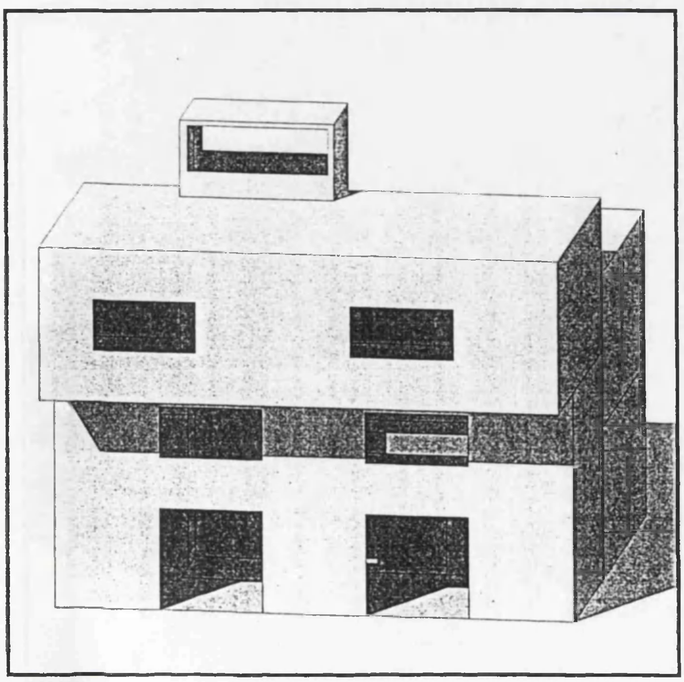




Proposed model, Tripoli.

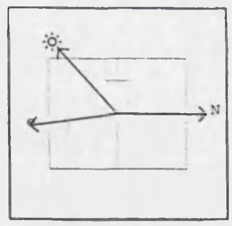
16 Jan 13:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 202.48 alt = 33.06
Eye : azi(y) = 262.00 alt = 12.00





Proposed model, Tripoli.

16 Jan 15:30 Eye view
Site Latitude = 32.50
Longitude diff. = 0.00
Model Bearing = 270.00
Sun : azi(N) = 228.86 alt = 18.14
Eye : azi(y) = 262.00 alt = 12.00



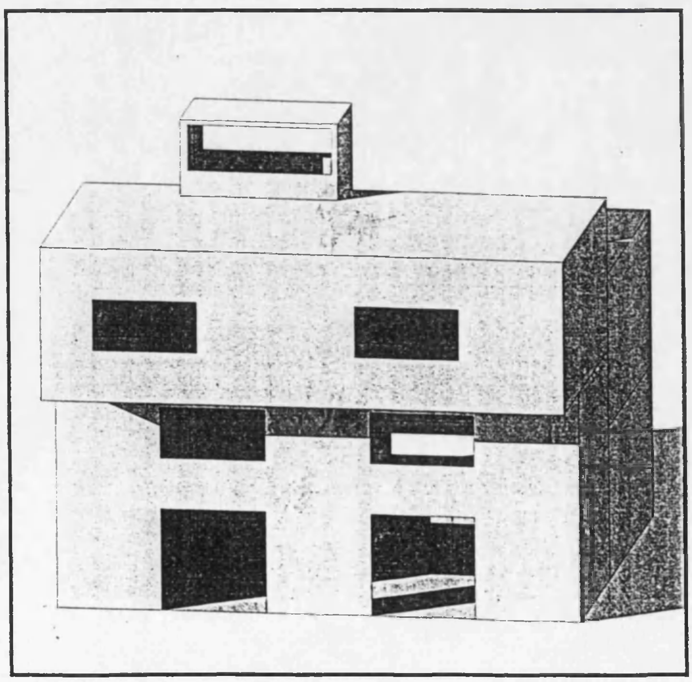
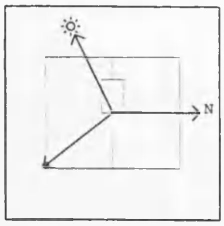
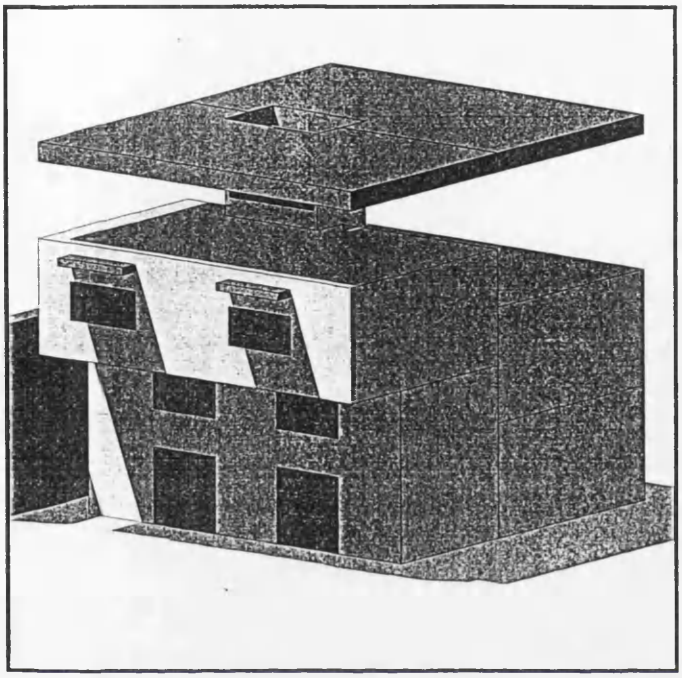


Plate (24 b)

Proposed model, Tripoli.

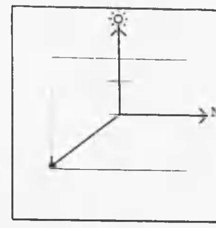
16 Jul 13:30 Eye view
Site Latitude   = 32.50
Longitude diff. =   0.00
Model Bearing   = 270.00
Sun : azi(N) = 244.49 alt = 68.22
Eye : azi(y) = 232.00 alt = 12.00

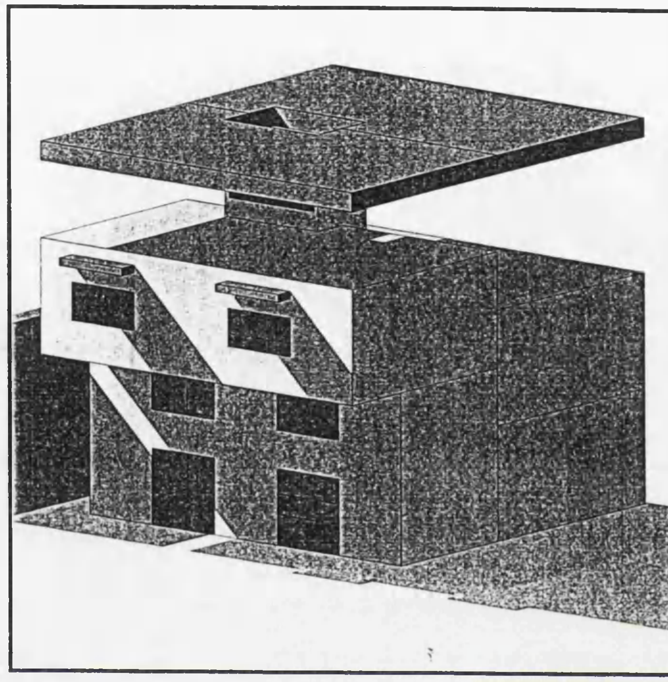




Proposed model, Tripoli.

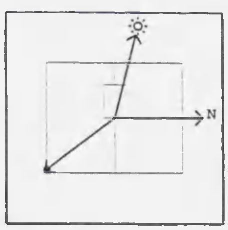
16 Jul 15:30 Eye view
Site Latitude   = 32.50
Longitude diff. =   0.00
Model Bearing   = 270.00
Sun : azi(N) = 269.42 alt = 43.57
Eye : azi(y) = 232.00 alt = 12.00





Proposed model, Tripoli.

16 Jul 17:30 Eye view
Site Latitude   = 32.50
Longitude diff. =   0.00
Model Bearing   = 270.00
Sun : azi(N) = 284.00 alt = 18.52
Eye : azi(y) = 232.00 alt = 12.00



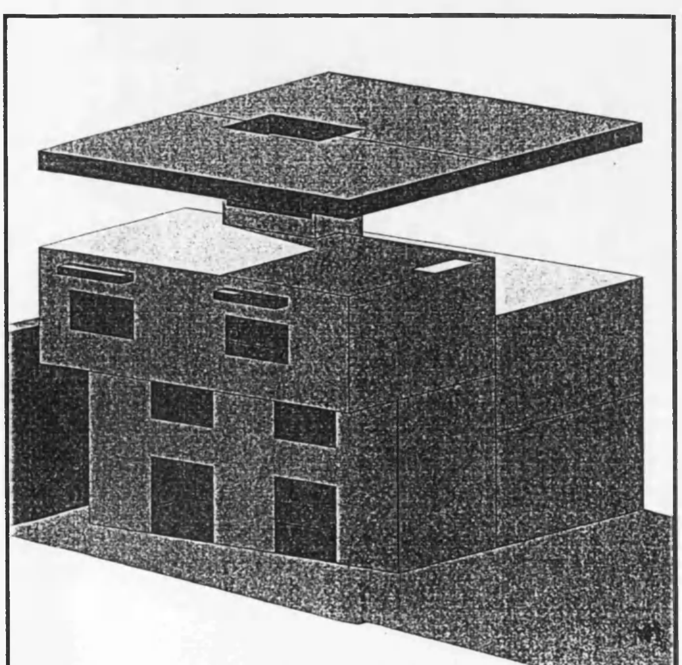


Plate (24 c)

5.2.2 The proposed cooling system

As illustrated in the bioclimatic chart of Tripoli, cooling is required at two levels: First, during daytime, where the peak external temperature is above the natural ventilation zone i.e. it normally requires a mechanical cooling system. Second is during night, where the temperature drops and with natural cross ventilation alone the comfort zone can usually be achieved.

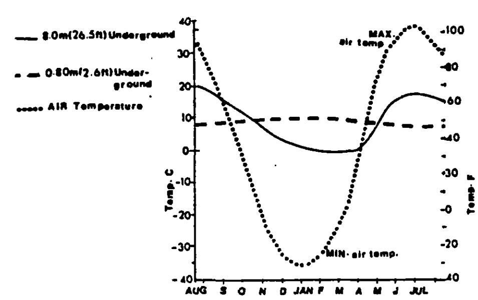
The following section describes the proposed passive system principally utilised for cooling during daytime. but will also be useful for the extreme natural occasions when the temperature remains at a very high value.

Cooling Tube System.

As described in chapter 4 the efficiency of such system depends on two basic elements: first, is the nature of the soil, where surface should be treated and modified to enhance cooling of the subsoil; and second is the design of air cooling tube itself.

a)Nature of the soil

Tripoli soil is mainly a mixture of clay, sand and fibrous matter This composition may differ from one site to another. However, for the purpose of the analysis this study adopts the CSES recommendation of the ground temperature that is based on the University of Minnesota, underground temperature study, 1979 as equivalent to Tripoli's ground



Temperature variations decrease with depth (Minneapolis-St. Paul area) (source: University of Minnesota, 1979, p. 53).

Figure 43

Tripoli's ground temperature, Figure (43). The underground temperature at depth of 2 m drops to 20°C, in June, while the external air temperature is about 37°C to 40°C. The soil temperature, at depth of 1.2m can be reduced by up to further 5.5K and a mean of 1.7K if the surface is covered with a long grass, as indicated in Kusuda's experiments(see chapter 4).

Thus by using such ground cover the soil temperature will typically drop to nearly 18°C. at depth which is not too overuse in terms of excavation.

b)Tube system design

The general principals underlying such a system in this particular location, where summer humidity is quite high as well as temperature, have been outlined in chapter Four.

The required cooling tube system proposed in the model is to be in total 14 pipes laid in parallel pattern with at least 1 meter spacing. The pipe length is 15 meter long in order to achieve reasonable dehumidification, and a diameter of 25 cm embedded at depth of 1.5 and 2.5 meters. Plats (24), (25) and (26).

Material of the tube

Steel and plastic have been widely used as materials for the air cooling tubes. Their non-hygroscopic properties causes an accumulation of condensation on the surface of the tube. This requires a particular slope leading to a sump point for the purpose of collecting the condensation. As described in chapter 4, using unglazed clay pipes should prevent the problem of surface condensation as moisture condensed out from the air will be absorbed and transmitted through the clay to the soil. This in turn helps in reducing the soil temperature, as the earth thermal conductivity increases greatly when it is wet. As a result the outlet temperature may be reduced to nearly the soil temperature which increase the air cooling tube efficiency. and also, as indicated in chapter 4 the relative humidity of the air at the point of delivery should be environmentally acceptable.

Figures (44) illustrates the difference between the use of using non hygroscopes and hygroscopic material. The psychometric chart indicates the effect of using the non-hygroscopic material, with a fairly modest drop in temperature and still rather high range of RH values.

Chart, explains the possibility of the temperature drop and the relative humidity effect in the hygroscopic material such as clay. In this state the absolute moisture content will inevitably be reduced while the relative humidity will still be in a question that requires an experimental test.

Air flow technique.

The air flow will be as result of the passive stack effect generated from the difference in levels of the inlet and the outlet and the temperature difference. It can be roughly calculated as follows:

$$\mathbf{VFRs = 0.171\sqrt{[H(\Delta T)]}\ A_1.A_2/\sqrt{(A_1^2+A_2^2)}.\ (m3/s)}$$

A1 = Inlet opening for the underground tunnel, A2 = outlet at top of staircase tower, H = is the average height between the outlet and inlet.

The inlet opening refers to the total pipe diameter, whereas the outlet is related to the end opening at the top of the staircase tower. In this system 14 pipes with 25 cm diameter the total inlet opening is about 0.069 m^2. The outlet opening through the staircase tower window with area of $2m^2$. Thus the air flow rate can be adjusted through the outlet opening by design an adjustable window.

The expected cooling of air delivered to the house

The expected cooling totally depends on the system, sufficiency. Using the described calculation procedures of both the Princenton Energy Group. and Goetsch, Petersons, and Muehling experiment (Givoni, 1994, p222):

First: according to computer simulation developed by the Princenton Energy Group (PEG), assuming the correction for climate can be through the soil treatment.

Expected cooling (kWh) = 0.8*F + 2.54*D + 16.1*L + 28.5*Cond + 0.92*HC

Where F= air flow (m3/hr), D= Diameter (cm), L= Length (m), Cond = Soil Conductivity (w/mK), HC=Soil Heat Capacity (Wh/m3K)

E.C.(kWh)= 0.8* 2500 + 2.54 * 25 + 16.1 * 210 + 28.5 * 0.55 + 0.92 * 600 = 6012 kWh

Second: the comparison with the results of Goetsch, et al. experiment. The study is conducted in a similar climate with a similar technique of air cooling tube. Table (9) illustrates the comparison:

systems	external Temp.	Soil Temp.	out let Temp.
G,P,M.	40.6	23	32.2
Tripoli	37	22	29.34
Tripoli	37	18*	24

*The temperature of the modified soil.(covered with vegetation)

according to this the expected cooling can be calculated .
The calculation in chapter 6 show how a delivering temperature of 24C can be effective in cooling during a peak diurnal period in summer.

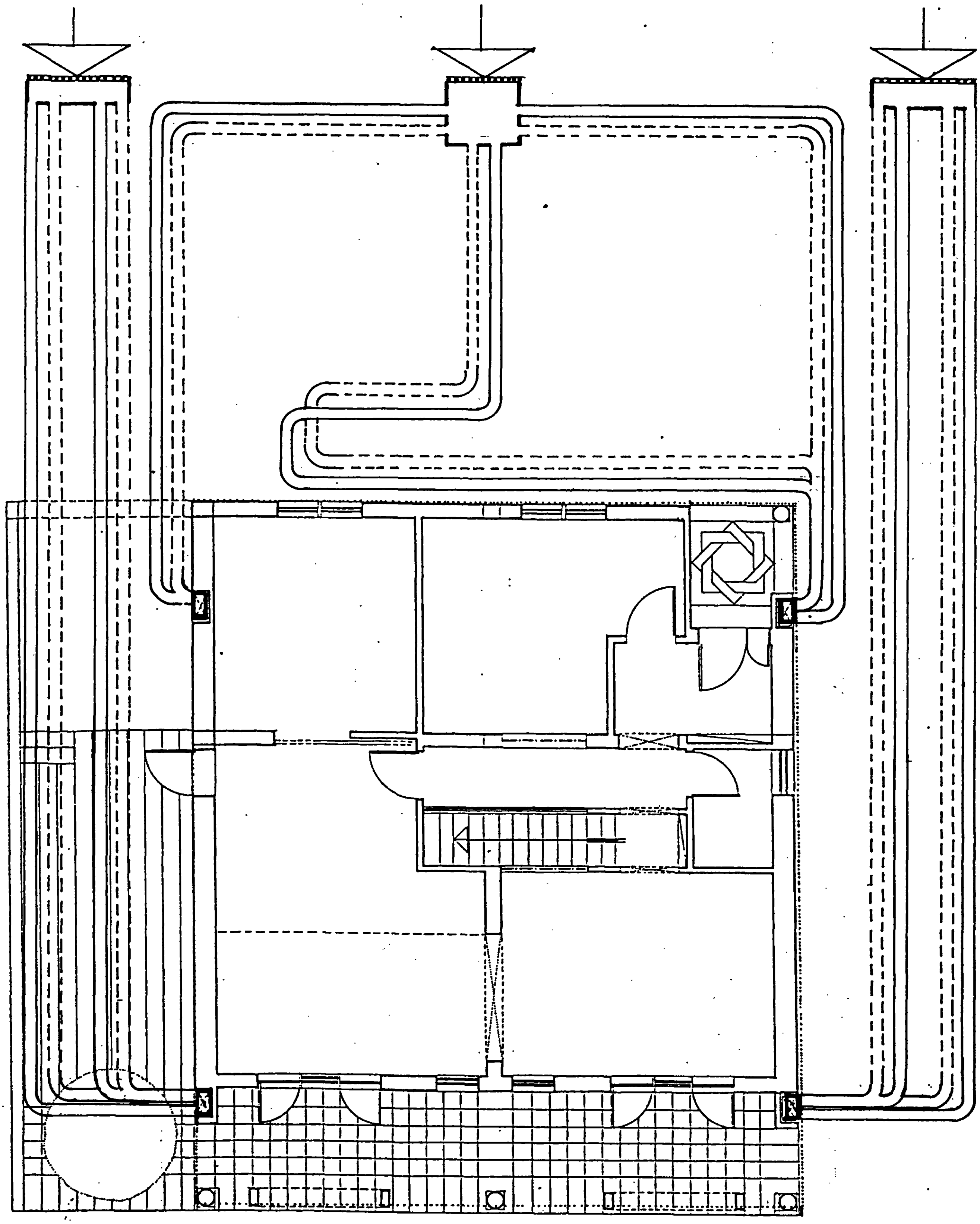
b- Nocturnal cross ventilated cooling .

This will occur at night, when the ambient temperature is low enough to cool the fabric and occupants. The value of flow rate can roughly as following

$$\mathbf{VFRw= 0.827 \sqrt{\Delta p} * A1*A2 / \sqrt{A1^2+A^2}} \quad \text{(m3/s)}$$

Air flow through opening in series in the building is due to the wind pressure (Δp), where Δp is the pressure difference Pa or N/m2). this is equal to the velocity pressure of the free wind Pw. Pw = 0.613 V^2 . V= is the wind velocity .A1 = inlet opening area. A2= outlet opening area.

Chapter 6 then examines how affective this would be relative to the heat balance equation.



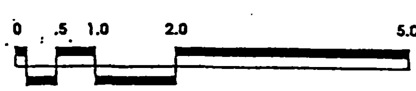


PLATE 24

EARTH COOLING SYSTEM
CLIMATE - CONSCIOUS PROTOTYPE

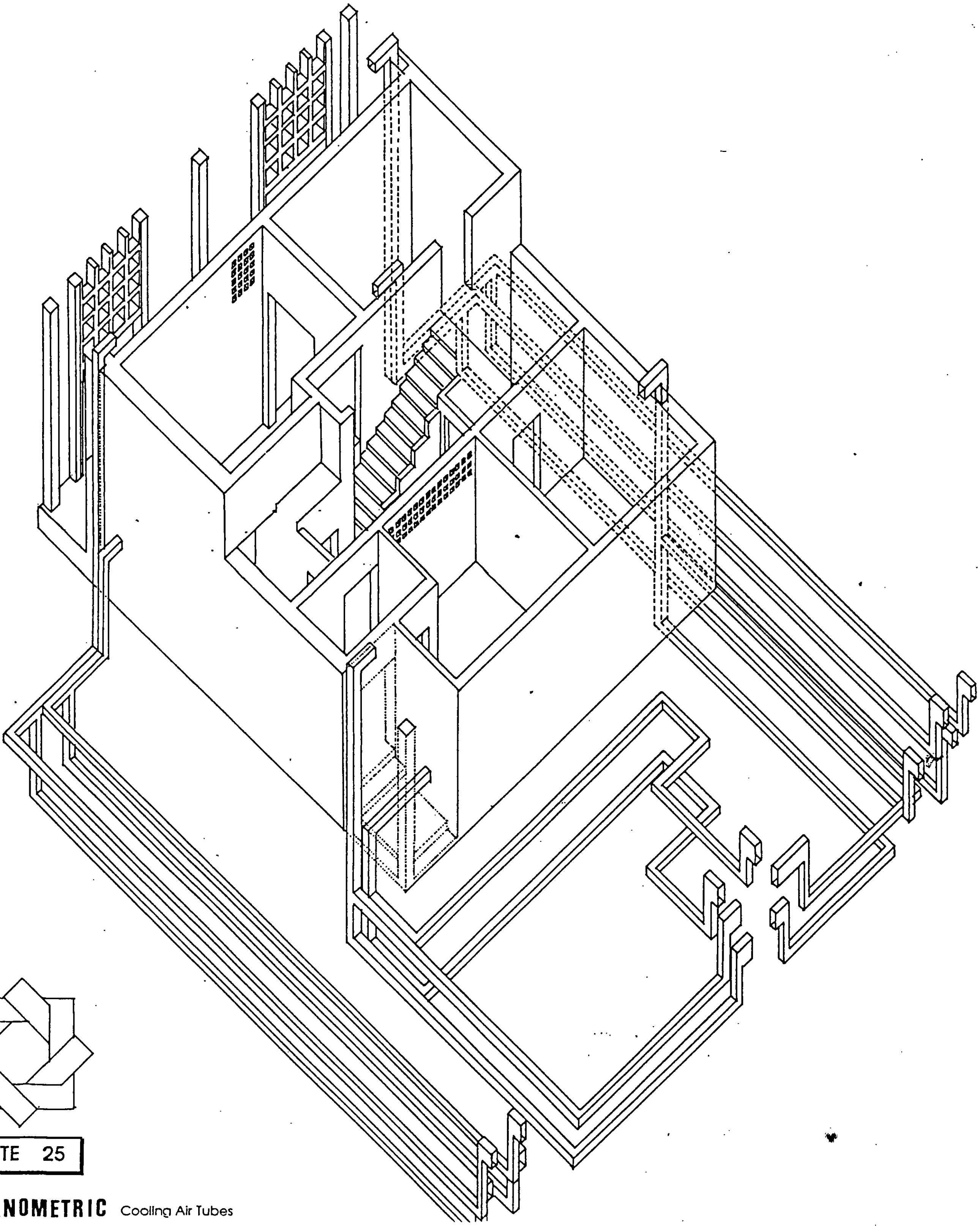


PLATE 25

AXANOMETRIC Cooling Air Tubes

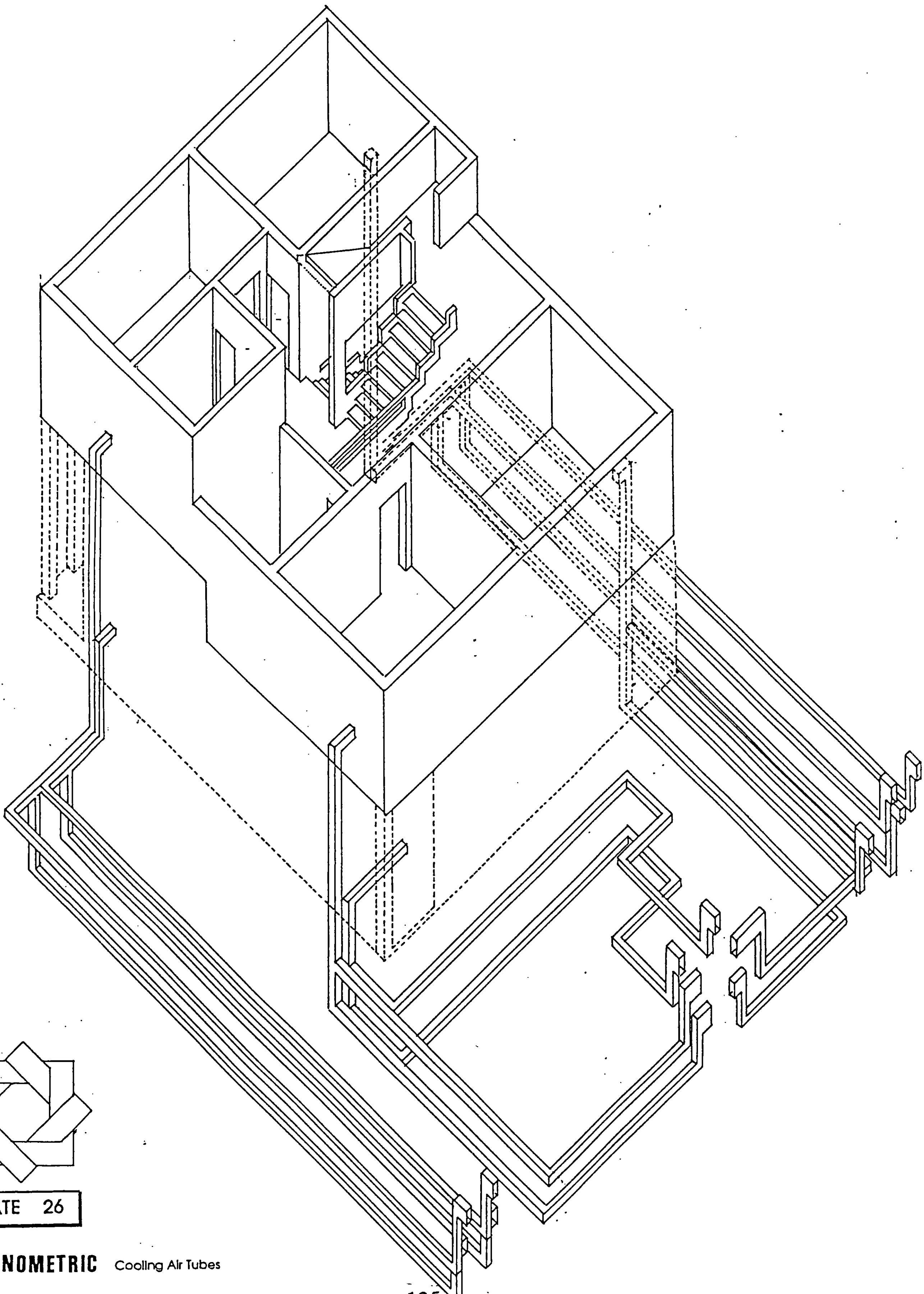


PLATE 26

AXANOMETRIC Cooling Air Tubes

PSYCHROMETRIC CHART

NORMAL TEMPERATURES

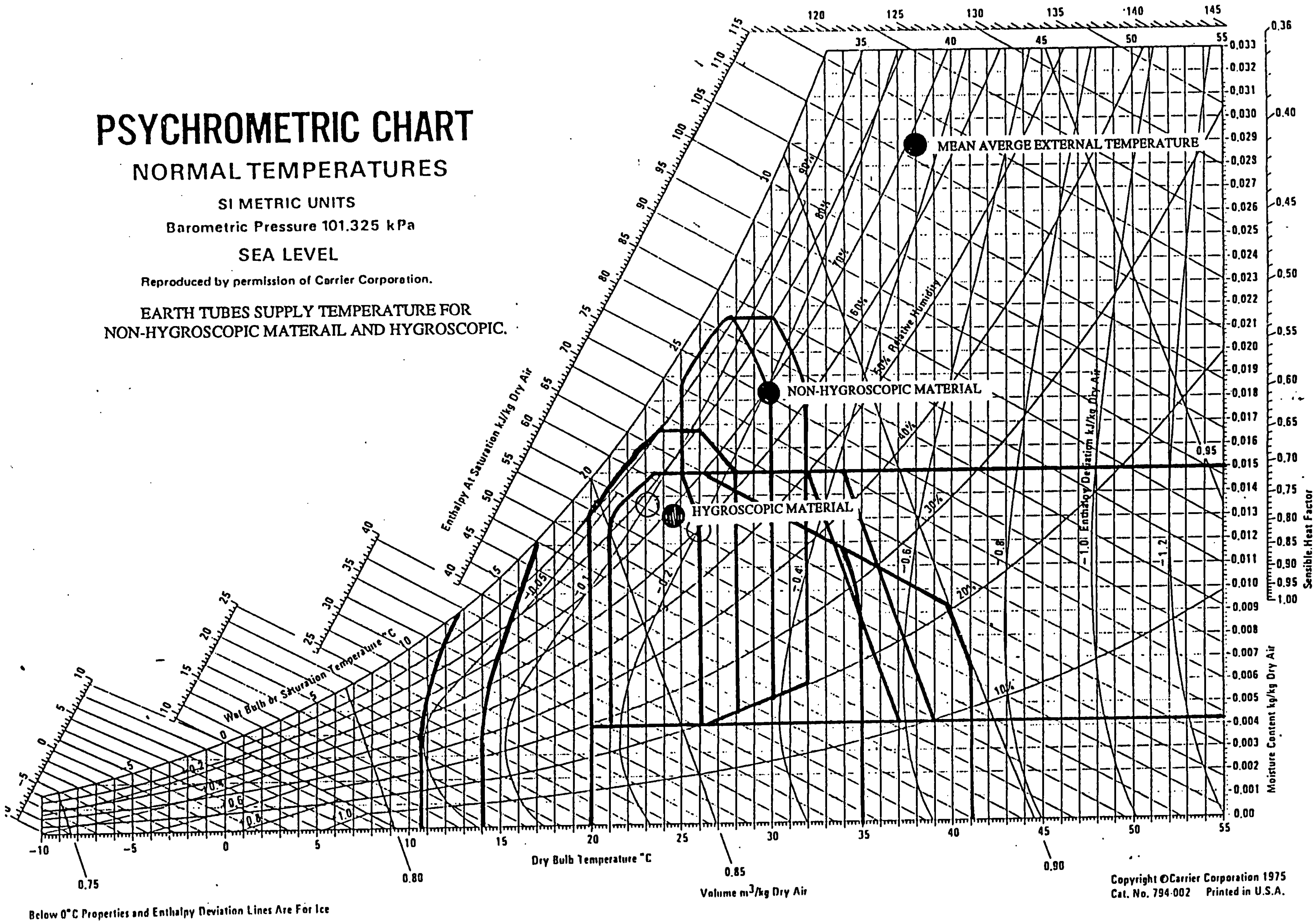
SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL

Reproduced by permission of Carrier Corporation.

EARTH TUBES SUPPLY TEMPERATURE FOR
NON-HYGROSCOPIC MATERAIL AND HYGROSCOPIC.



References;

1-Expert report on the old town of Tripoli, Tripoli's Municipality, Tripoli, 1982

2-Solar House , CSES Report Vol 1. Tripoli 1991.

3-Interview with Pierre d'Avion , London, April 1995.

4- Givoni, B., Passive and low energy cooling of building, Van Nostrand, Newyork, 1994.

5-Schmitt, Gerhard, Macro Computer Aided Design, for Architects and Designers, John Wiley &Sons, 1988

6.0 THERMAL PERFORMANCE ANALYSIS

6.0 THERMAL PERFORMANCE ANALYSIS

6.1 Manual Methods

With the existence of computers, manual methods considered the second way of analysis. Although crude, the analyst in more uniformly in control of error-checking then with computers where there may be misplaced confidence, a machine taking over after the initial input, and the epithet "rabbish in, rabbish out" applies, Thus manual methods have their place in providing "ball-park" values; which may if necessary be further refined by computer. In this study the further refinements have been concentrated on summer cooling, since this is the difficult thermal nut to crack;

Manual methods will applied in calculating to conditions
6.1.1 Winter condition.
6.1.2 Summer conditions.

6.1.1 Manual calculation Winter Conditions

This study appraises the building performance in winter through a method included in the European passive solar handbook (Energy in architecture),"the New Method 5000". This method is used to predict the auxiliary heating required for any specified month by subtracting the useful heat gains from the gross heat losses.

The new method 5000 has been used as basis for analysis of the thermal performance of the proposed model, in December and January.

1-Stage 1- The heat loss rate

The heat loss rate calculation is divided in to four steps

a- Through the opaque walls and roof surfaces
b-Through the glazed surfaces.
c- Through the floor.
d- Through ventilation and infiltration.

A) The heat loss rate for the exterior walls and roof is summarised as followings;

Heat flow rate = $\Sigma A\ U$ (W/K).

Element	Area (m^2)	U(W/m^2)	Heat loss (W/K)
South wall	57	0.2	11.4
North wall	48	0.2	9.6
East wall	70	0.2	14
West	70	0.2	14
Roof	120	0.3	36
Total (wall roof)	365	0.23	85

B)Heat loss rate through glazing area . “Double glazed windows”

Element	Area (m^2)	U (W/m^2K)	Heat loss (W/K)
South window	18	3.3	59.4
North window	8	3.3	26.4
East window	1	3.3	3.3
West window	1	3.3	3.3
Total widows	28	3.3	92.4

C) Heat-Loss rate from floor slab, by the following formula

Heat loss rate = L*k ,where ,if the length of the edges L is 40 m and conductivity k=1.2 W/mK,

This may be cross checked using CIBSE method (1980):

$U = 2\lambda e\ B/0.5\ b\pi * \text{artanh}\ [0.5b/(0.5b+0.5w)] = 0.59\ (W/m^2K)$

Where λe= The thermal conductivity of the earth, = 1.4. (W/mK); a,b= dimensions of the floor; w= thickness of surrounding wall = 0.3m; and B= is constant =exp (0.5b/a).a = length the greater dimension of the floor

Adding 5 cm of insulation to the edges, the U value is reduced to 0.45 W/m^2K

Floor slab	Area m^2	U-value w/m^2k	heat loss w/k
	100	0.45	45

D) Heat loss rate from ventilation infiltration,

Ventilation heat loss rate Qv

$$Qv = 0.34*qt\ (W/K)$$

where the qt is the volume flow rate for example, for infiltration rate of 0.3ac/hour and for a volume of 660 m3 , The flow rate qt = 198 W/k .

Qv= 0.34*qt=0.34*198 =67.3 (W/K)

Sum of losses (daily rate) *(W/K)* hours of heat loss

	Area m^2	heat loss rate W/K
Wall and Roof	365	85
External Windows	28	92.4
Floor slab	100	45
H-L from ventilation		67.3
Total heat loss rate		289.7

The daily average total daily heat loss rate (LL)

$$LL=(24* \text{heat loss})/1000 \quad \text{kWh/Kday)}$$

and average daily heat loss rates are converted to average monthly heating load.(Qng)

$$\mathbf{Qng=LL*DDm \qquad (kW/K)}$$

where DDm =(tt-to)*N . where N= Number of days in month.,tt= required indoor temperature(19), to=the average monthly outdoor temperature

Heating Month number of days	31-Dec.	31-Jan
Average exterior temp to °C	13	12
Degree days DDm (K-day)	186	217
heat loss per day LL (kWh/Kday)	6.95	6.95
Load Qng (kWh/mo)	1292.7.	1508.2

*This is only for the peak heating load for the year where the (minimum) average temperature

2-Stage 2 Heat gain rate

a) The Heat gain from direct solar gains (Φdg) (kWh/day) can be found from the windows areas and calculation of transmitted solar radiation as described in chapter two.

$$\mathbf{\Phi dg = E*A* Sf}$$

E= the average incident daily radiation in kWh/m^2 for the orientation and tilt of each window. Sf = Shading Factor, including allowance for net curtains. Small East facing windows to toilets are ignored.

Glazing properties			Dec.	Jan
		E (kWh/m^2 day)	3.05	3.23
Net area =17.1 m^2	tilt 90	Sf	0.64	0.63
		Φdg kWh/day	33.88	34.8
Net area=7.2m^2		E (kWh/m^2 day)	0.796	0.83
	tilt=90	Sf	0.63	0.62
		Φdg (kWh/m^2 day)	3.61	3.71
Total direct gain	Φdg (kwh/day)		36.89	38.51

b) Incidental or casual heat gain rate ΦI (kWh/day):, the amounts are dependent on the occupancy of the house and on the way hot water, electric lighting and appliances are used. It may be estimated, knowing the number of occupants and type of buildings .(the values are given in Watts averaged over 24 hours).(BREDEM,1985)

source	W
Metabolic = 62N	372
Water heating =16N+25	121
Cooking Gas	136
Electrical appliances (total)	120
lighting /medium house children	37
Total gains	786

The internal heat gain ΦI = 786*24=18,864 Wh/day, i.e. 585 kWh for December and January.

The Sum of useful (solar and incidental) heat gains

$\Sigma \Phi = \Phi I + \Phi dg$ = (kWh/month)

i.e. For December =1,729 KWh, for January = 1,779 KWh

3-Stage 3

Calculating the useful fraction of gains η ($0<=\eta>=1$)

This will be found through the thermal inertia classification and the buildings heating Gains / load ratio(GLR).

$$\mathbf{GLR = N\Sigma \Phi / Qng}$$

The thermal inertia classification is derived from the ratio I (useful thermal mass/floor area Kg/m^3). In this insulated building the I is calculated to be 150kg/m^3 (the thermal mass per unit area of the material located between the layer of the insulation and the heated space).

From Figure (45 a) and (45 b) according to this ratio the building is classified as category 4

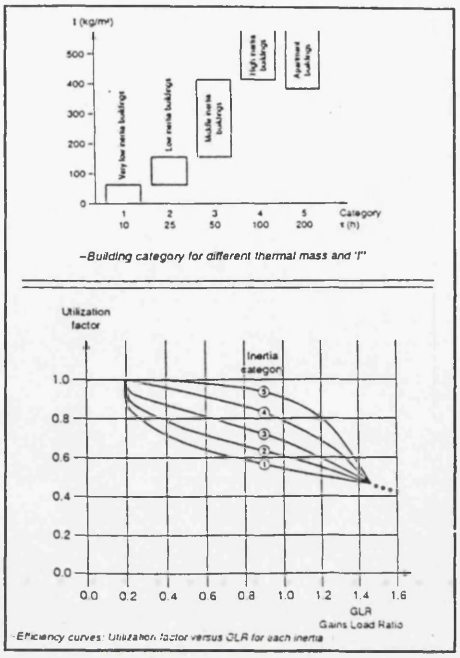


Figure (45 a,b)

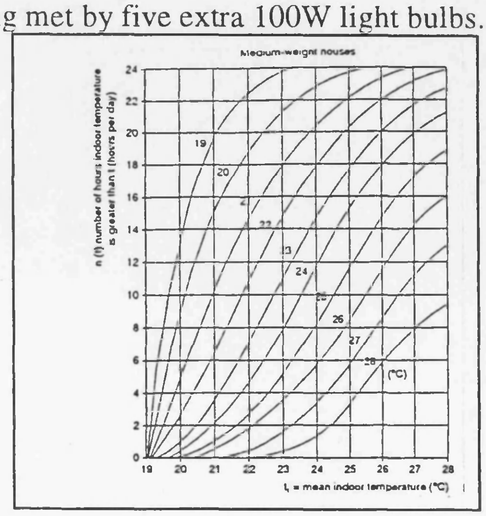
Thence the useful fraction η of gross solar and casual gains is found by the GLR and the Inertia category for the building, as shown in Figure(45,b) 312

numbers of days N	31-Dec.	31-Jan.
solar daily Gain kWh/day ΦSolar	36.89	38.51
Daily total gain kWh/day Φ	55.75	57.37
Monthly total gains kWh/month N Φ	1729	1779
Load Qng (kWh/mo)	1293	1508
Gain load ratio GLR	1.34	1.18
Utilisation factor η	0.62	0.70
Useful gains SQ	1072	1245
Auxiliary heating load kWh/month Qaux	262	263

From this we find that the auxiliary load is under 9KWh per day, or if the house is occupied for about 2/3 of the daily cycle, the load for the entire house is about 0.5 KW for the occupied hours, i.e. capable of being met by five extra 100W light bulbs.

4 Stage 4

The last stage is checking comfort condition, as the required heating temperature may be increased from the design to a discomfort level. This is found by the following equations and by using chart figure(46):



–Overheating assessment graph

$$twh = to + (tt - to)\ GLR$$

and the average indoor temperature **ti** is deduced from

$$ti = twh + (tt - to)(1 - \eta\ GLR)$$

Where twh = internal temperature without heating . to= the average monthly outdoor temperature. tt= thermostat set point temperature assumed to be 19 °C. GLR = Gain load ratio

	Dec.	Jan.
Internal temperature without heating **twh (°C)**	21.04	20.26
The average indoor temperature **ti** (°C)	22.0.6	21.48

The chart indicate that for medium weight building, and internal temperature, ti=22°C the temperature will be below 19°C in less than 2 hours of the day.
This means that the theoretical mean design temperature of 19 °C is closer to 21.6°C. The conclusion to be drawn is that the modest theoretical space heating load found above is driven by lower night temperatures and an expectation of low utilisation due to the will insulated shell. So if some of the solar gain is not dumped, the house will tend to be rather too warm for part of the day. Therefore, a more liberal ventilation regime during the day could avoid any overheating, and any residual evening auxiliary load would depend on the effectiveness of diurnal stored solar radiation.

6.1.2 Manual calculation for summer performance

The thermal balance equation has been used to appraise the thermal performance of the building in an extreme summer condition, The material of the building envelope is specified to damp and delay heat flow (see chapter 4, materials), using concrete block a structural material and polyurethane as insulation. The evaluation will be a "snapshot" focusing on the peak solar gain of the hot season according to the maximum solar irradiation from 12.00 -15.000 in June, taken as solar time. This will be calculated in two situations.

1- The diurnal evaluation of thermal performance, firstly in terms of envelope in addition to the passive stack effect, and secondly including the influences of the cooling earth tubes.
2-The nocturnal cross ventilation.

1- Daytime Evaluation of the building's thermal performance.

$$Qc+Qi+Qs+Qso = \sum AU\ (ti-teo) + .33\ n\ V\ (ti-to)$$

where Qc = cooling load calculated as negative		W
	Qi = incidental gains in	W
	Qs =solar gains through the glazing area	W
	Qsa =solar gains through opaque surface	W
	A = area of the element	m^2
	U = The transemittance coefficient	$W/m^2.K$
	n = number of air changes per hour	ac/h
	V= volume of the cooling space	m^3
	ti = internal temperature	C
	teo = equivalent outdoor temperature	C
	corresponding with each U-value	

STAGE 1.

1) The heat flow rate through building's envelope ,

The heat flow rate for the exterior envelope ,walls ,windows and roof and floor by using the following formula

Heat flow rate = A U

1-a) Heat flow rate through walls

With concrete construction with polyurethane will achieved the 0.2 as U value for the walls and 0.3 for the ceiling .Each heat flow rate will driven by the (ti-teo) defer in accordance with the heat balance equation given above. In this case given the wall construction is the same for all facades, there are only two values for Teo, and Ti is assumed to be 27°C, a maximum desirable limit in terms of thermal comfort.

Element	Area (m^2)	U (W/m K)	Heat flow (W/K)	Teo
South wall	57	0.2	11.4	29
North wall	48	0.2	9.6	29
East wall	70	0.4	14	29
West	70	0.4	14	29
Ceiling	120	0.3	36	30
Total (wall roof)	**365**		**85**	

1-b)The heat flow rate through glazed area

In summer the use of shutters is very essential in order to reduce the amount of heat therefore, the glazed area will assumed to be reduced in the extreme conditions to 50%, Hence the area for the south glazing will be 8m^2 ,and for the north glazing 4 m^2. The U value for the glazed area = 3.3 W/m^{2}K ,while the U value for the timber shuttered area =0.12 W/m^{2}K.

Element	Area(m^2)	U (W/m^{2}K)	Heat flow (W/K).
South glazing	9	3.3	29.7
south win + shutter	9	0.12	1.08
north glazing	4	3.3	13.2
north win + shutter	4	0.12	0.48
east glazing	0.5	3.3	1.65
east win shutter	0.5	0.12	0.06
west glazing	0.5	3.3	1.65
west win shutter	0.5	0.12	0.06
total	**28**		**47.88**

1-c) Heat-Loss rate from floor slab, by the following formula

$$U = 2\lambda_e B/0.5\, b\pi * \text{artanh}\,[0.5b/(0.5b+0.5w)] = .59$$

λ_e= The thermal conductivity of the earth = 1.4; a,b = dimensions of the floor a.>b; w= thickness of surrounding wall =0.3m; B= is constant = exp (0.5b/a).

a = length greater dimension of the floor

According to table (10) (table 2 BRE information paper), with insulation edge of 5 cm, the U value is reduced to 0.45 W/m^{2}K.

Floor slab	Area (m^2)	U-value (w/mk)	heat loss w/k
	100	0.45	45

Finally the total heat rate flow

By summing the heat flow rate in the following table

Source of heat loss	Area m^2	heat loss rate W/K
Wall and Roof	365	85
External Windows	28	47.88
Floor slab	40	45
Total heat flow rate		**177**

AU= 178 W/K

2)The internal heat gain (incidental gains) **Qi**

Here since the calculation is only for a specific 'snapshot' in summer the internal gains are lower than in the winter scenario above,

source	W
Metabolic = 62N (N=4)	248
Water heating =16N+25 (N=1)	41
Electrical appliances (total)	57
Total gains	346

Qi for 'snapshot' = **346**

3- Solar Gains

3-a) The solar heat gain through the glazing area -Qs

Solar gains through glazed area affect the building in two ways, first by short wave radiation, where the instantaneous solar gain at the peak time is multiplied by the surface factor and the short wave shading coefficient; second, by the long wave radiation, where the instantaneous gain time lag hours after the time in question is multiplied by the long wave shading coefficient . However the intensity of the incident solar radiation is likely to be affected by differences in atmospheric haze To allow for this, the sum of the short wave and long wave gains should be multiplied by a haze factor and finally by a seasonal factor .So in this calculation ,the haze factor for Tripoli is 1.05 , the seasonal factor is 1.0, while the time lag ii taken as 2.8 hours and the surface factor as 0.46

Glazing orientation	South	north
Net glazed area	7.6	3.6
Shading coefficients , Short wave	0.7	0.7
surface factor	0.46	0.46
global irradiation at 12.00, (W/m²)*	263	263
short wave component (W/m²)	84.68	84.68
Shading factor long wave	0.12	0.12
global irradiation at 15.00 (W/m²)*	156	156
long wave component (W/m²)	18.72	18.7
haze factor	1.05	1.05
South & long wave component (W)	825.13	390.85

* the global irradiation is calculated with respect to the shading device and sun's incident angle at noon the Incident angle(i) could be determined by

$$\cos i = \cos \beta * \cos \gamma$$

where (i) is the incident angle.(β)is the Solar altitude angle (γ)The wall-solar azimuth angle.

At 12 noon on the south surface the incident angle = 80 degree and with the efficiency of the shading device there will be no direct irradiation on the windows , while at 15 o'clock the incident angle is = 90 degree. which also means there is no direct irradiation on the windows.

Plate (28) shows the incident angle on the model at 15 o'clock.(ESP < Insolare)

Qs =1216 W

3-b)Solar heat gain through opaque surface Qso

Qso=AU (tsa-ti)

tsa = solair temperature. ti = outdoor temperature, taken here as 27°C to reresent the maximum permissable in terms of comfort. Since the snapshot is concerned with the period 12.00-15.00, and the envelope has a time lag of approximately 9 hours the solar temperature may be taken as outdoor temperature (There are posture radiation reading at 06.00, close to dawn, but they are not enough to rise Tos above To.) mean value for To in June is 27.68. Thus the solar gain through the fabric during the snapshot is negligible relative to a maximum internal design temperature of 27 (see table below) and may be ignored . The heat balance equation will in any case take account of heat flux from outside to inside or vice versa by means of the (Ti -Teo) temperature differential applicable to each opaque component of the envelope.

Element	Area m^2	$U(W/m^2K)$	Heat loss(W/K)	solair Tso	Tsa--Ti	Qsa W
South wall	57	0.2	11.4	27.7	0.7	7.76
North wall	48	0.2	9.6	27.7	0.7	6.72
East wall	70	0.2	14	27.7	0.7	9.8
West	70	0.2	14	27.7	0.7	9.8
Ceiling	120	0.3	36	27.7	0.7	25.20
Total (wall roof)	364		85			59.28

* the solair temperature is considered with the time lag which is in this structure = 9 hours; i.e. at 6.00

It may also be noted that the impact of peak solar radiation on the envelope, which occurs at solar noon will not be felt until 21.00, and by this time the outside temperature has dropped back from its 15,00 peak of 39°C to about 28.6°C.

Gains may then be summarised in the table below

Source	W
Incidental heat gain Qi	346
Solar heat gain through opening Qs	1216
Total heat gains QT	1562

4) Heat loss due to ventilation.

The 'snapshot' is assumed to be taken for a hot, still day, heat flow by ventilation may be assumed to be by the passive stack effect which depends on the difference between outside and inside temperature, the height between the outlet and inlet, and their size. This can be found by the following equation

$$\mathbf{VFRs = 0.171\sqrt{[H(\Delta T)]}\ A_1.A_2/\sqrt{(A_1^2+A_2^2)} \qquad (m^3/s).}$$

A1 = Inlet opening through the windows shutters.
A2 = out let is through the upper wind scoop opening .
H = the average high between the outlet and inlet = 6 m

The analysis initially plays 'devil's advocate' by losing the impact of diurnal ventilation, in the knowledge that the high To value during the 'snapshot' will have the effect of increasing rather than reducing the cooling load, Quite large openings of 1m2 and 2m2 are used in the knowledge that substantial air movement may at least have a beneficial effect in terms of thermal comfort. Hence:

$VFRs = 0.171\sqrt{[6(38.4\text{-}27)]}\ 1*2/\sqrt{(1)^2+(2)^2} = 1.265\ m^3/s$

Air flow $=1.265*3600 = 4554\ m^3/h$

therefore the change per hour for 660 m^3 volume will be 6.9 ac/h.

Heat flow by ventilation 0.33nV = 1503 W/K

Returning to the heat balance equation :

Qc+Qi +Qs + Qso = ΣAU (ti -teo)+.33 n V (ti -to)

Qc + 1562 = 49 (27-29) + 36 (27-30) + 47.88 (27-38.4) + 1503 (27-38.4)

Qc= -17886.032 (W)

The equation clearly demonstrates the folly of opening windows during peak diurnal period, and that even with all windows closed to give infiltration through cracks, the heat gain would be roughly equivalent to that conducted through the windows. Also the comfort motive is erroneous, because although the air movement night raise the tolerable temperature limit by some 2K to 29°C, this would still be a substantial cooling load; and any plant is stalled to meat this load would provide an adequate degree of air movement.

Therefore, to achieve a thermal balance with Qc = 0, without cooling plant the only possible way is to introduce air which has been passively cooled below the target value of 27°C. Alternativcly, allowing the internal temperature to rise somewhat above 27°C may be acceptable for a short period in the early afternoon, but this would still entail substantial cooling of the ambient air.

STAGE 2

With the introduction of the earth tube cooling system, which has been described in chapter 5, the internal (supply temperature) will be nearly 24°C . This will effect the heat loss due to stack ventilation which is

$VFRs = 0.171\sqrt{[H(\Delta T)]}\ A_1.A_2/\sqrt{(A_1^2+A_2^2)}$.

A1 = Inlet opening for the underground tunnel = 7*0.1=0.7 m2
A2 = out let is through the upper window opening = 1.4 m2
H = the average high is the between the outlet and inlet = 6 m

$VFRs = 0.171\sqrt{[6(38.4-29.4)]}\ 1.4 * 0.7 / \sqrt{(1.4)^2+(0.7)^2}$.

Air flow =1.325 m3 /sec, 1.325*3600= 4770 m3/h

Therefore the change per hour for 660 m3 volume will be 4770 / 660 =7.22ac/h

Returning to the heat balance equation, this time the rate of ventilation contributes to cooling:

Qc+Qi +Qs + Qso = ΣAU (ti -teo)walls +ΣAU (ti -teo)roof+ΣAU (ti-teo)windows +0.33 n V (ti -to) (ventilation)+ 0.33 n V (infiltration)

Qc + 1562= 49 (27- 29) + 36(27-30) + 47.88 (27- 38.4) + 1572.5(27-24) +54.5 (27-38.4)

Qc=1782.5 W

The conclusion to be drawn is that the earth cooling is an effective strategy. if the 24°C can be achieved for the inlet air, the internal air temperature can be lowered to around 26°C. Alternativily if the inlet air is slightly more that 25°C, again zero cooling load is achieved at a mean internal air temperature of 27°C.

2- Nocturnal Cross Ventilation

The Teo values at night will rise above the external temperature as result of the structural thermal lag. Therefore the fabric will be allowing more heat gain to the inside than during the diurnal 'snapshot' However, since the mean external temperature in June is below 27°C from just after 22.00 until almost 6.00 (a mean of 24.45 °C from 23.00 -05.00)night cooling by means of cross ventilation or stack effect may offset the gains through the fabric. If incidental gains are 525W overnight and the ventilation rate is 1.5 ac/h;

Qc +525 = 49 (27- 34)+36(27-32)+47.88 (27-24.45) + 327 (27-24.45)

Qc= -1048 + 122.094+833.85 (W)

Qc= -92.056 (W)

This indicates that a ratio modest window opening regime could hold overnight temperatures down to 27°C. Alternatively, a lower temperature could be achieved if more windows were opened.

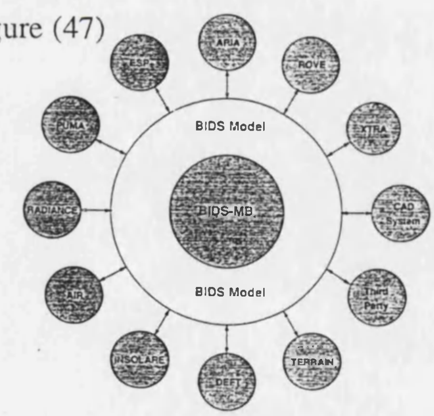
It should be remembered that although the above calculations are for average June conditions, since the climate of Tripoli dose not vary much from year to year, compared with a north European location, this may be taken as representative. Although the calculation technique may appear to be rather rudimentary the critical pieces of data with respect to the cooling capability of the earth-tube system has been verified using a sophisticated dynamic thermal analysis model that of ESP (Environmental Systems Performance), The background to which is described below.

6.2 CAD (ESP) application in appraising the thermal performance of a building.

The ESP (Environmental Systems Performance) of ABACUS is a design oriented thermal simulation appraisal programme, (ESP manual, 1992), which allows the building designer to appraise a design in terms of comfort and energy consumption. ESP uses a Building Integrated Design System, (BIDS) as the front and back-end to its simulation model, and has been declared by the Commission of the European Communities as their Reference Simulation Model. BIDS consists of a number of components which are now summarised, as follows in Figure (47)

1- BIDS-MB (BIDS- Model builder)
2-Performance Assessment Tools

Figure (47)



BIDS: Building Integrated Design System

1- BIDS-MB (BIDS- Model builder)

This can be defined as "a suite of integrated software tools which provide an interface for the creation and subsequent modification of BIDS, and consists of the following files, Figure (48):

a- Geometric file (XZIP).
b- Construction database file.(XCDB).
c- Configuration file (XCONFIG).
d- Function database file.(XZDB)

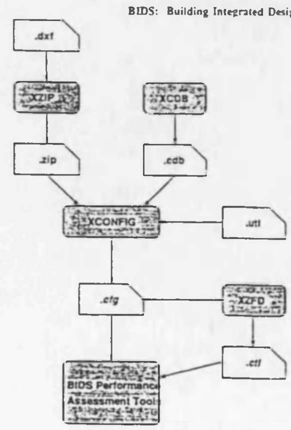


Figure (48)

The BIDS-MB System

2-Performance Assessment Tools

BIDS includes a library of software tools which will be activated at the designer's request. The tools that are required for thermal performance appraisal are summarised below.

a-INSOLARE: solar mapping / Insolation.

b-Air infiltration.

c-ESP$^+$: Building Energy Simulation.

The appraisal of the proposed model.

The appraisal of the model by ESP can be summarised as following;

1-Programme input for the model builder

a- Geometric file (ZIP).

In this file the building is defined as a 3-dimensional geometrical shape, divided into zones, one of which has its own details such as doors, windows, and opening. The model is divided into 7 zones according to function as follows. Plate (28).

-Zone 1 Living room.

-Zone 2 Kitchen.

-Zone 3 Reception room (guest)

-Zone 4 The stair case (lower part).**

-Zone 5 Bed room (This consist of the rooms on the south orientation).*

-Zone 6 Bed room (This consist of the rooms on the north orientation).*

-Zone 7 The stair case (upper part).**

*Considered as one zone in order to simplify the process since they both have the same function.

** Divided into two zones in order to identify the influence of buoyancy.

b- Construction database file (CDB).

The construction database file deals with information which describes the material of the building. This information can represent composite constructions formed from elements extracted from a standard database; or it could be a new, where the thermal properties are known have to be individually described. The material of the model envelope, (external and internal walls, ceiling, floors, roofs, windows and doors) is the same material that has been used in the manual calculations. This data is summarised in the output of the programmes (Appendix B)

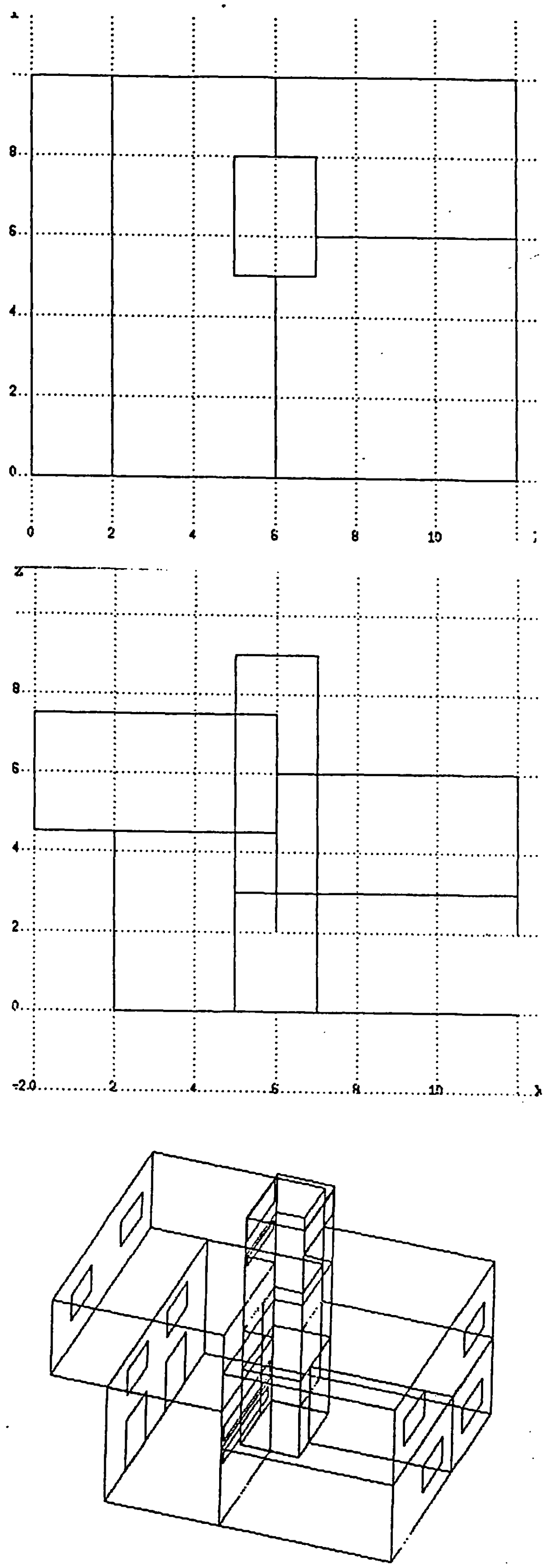


Plate (28)

c-Configuration

Configuration file define:

Zone volumes and surfaces to which specific constructional information is assigned.

- Simple geometry expanded into non-overlapping surfaces.

-Door and windows automatically matched for internal surfaces.

-Surfaces sorted by azimuth and elevation.

The previous two files (ZIP and CDB).are required, as input to XCONFIG, From this the follows files are generated; a zone geometry file (geo); a zone operation file (opr); a system Configuration file (cfg); and a geometry Analysis file.(tab)

The building location and orientation, as well as site position is given for Tripoli as discussed in chapter 2. The structure has been organised in terms of air circulation. Therefore the internal walls between the staircase and the living zone are assigned to (0) indicating no walls. This is also assigned to ceiling/floor between zones 4 and 7 , the lower and upper staircase. Internal windows are assinged to (0) to improve cross ventilation.

d- Function database file.(XZDB)

XZFD is a programme for creating and assigning functional data to zones which are stored in XCONFIG. This functional data includes occupant, lighting and equipment profiles, as well as casual gains, heating and cooling plant control and supply information.

The appraisal of the model by ESP can be summarised in terms of summer and winter control profiles. Winter has only one profile, indicating no specific heating control, in summer the profile is divided into three periods. ventilation inlets starting time and finishing time is distributed according to the different control laws; e.g. 00.00 -10.00 the need for cross ventilation is essential; while from 10.00 onwards the temperature gets high and therefore under ground cooling is introduced This will continue till 18.00 and then the third period is the same the first one.

2-Performance Assessment Tools

a-INSOLARE: solar mapping / Insolation.

After generating the model by BIDS-MD the INSOLARE generates solar shading and insolation information. This consist of a sun tracking algorithm and a hidden surface algorithm to generate and view shadow data for each surface of the model. The data for this file is done for Tripoli location and the model orientation this is shown in plates (29, 30)

In summer the obstruction file have been introduced ti indicate the effect of the green wall on the west of the model and the secondary green roof, However this is ignored in winter conditions as result of the vegetation which has been discussed before.

Proposed model, Tripoli.

16 Jan 13:30 Eye view

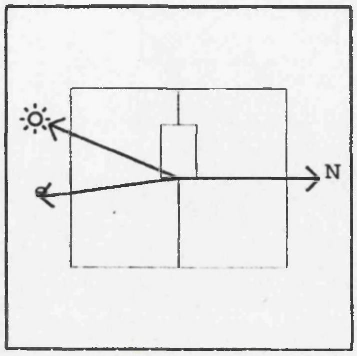
Site Latitude = 32.50

Longitude diff. = 0.00

Model Bearing = 270.00

Sun : azi(N) = 202.48 alt = 33.06

Eye : azi(y) = 262.00 alt = 12.00



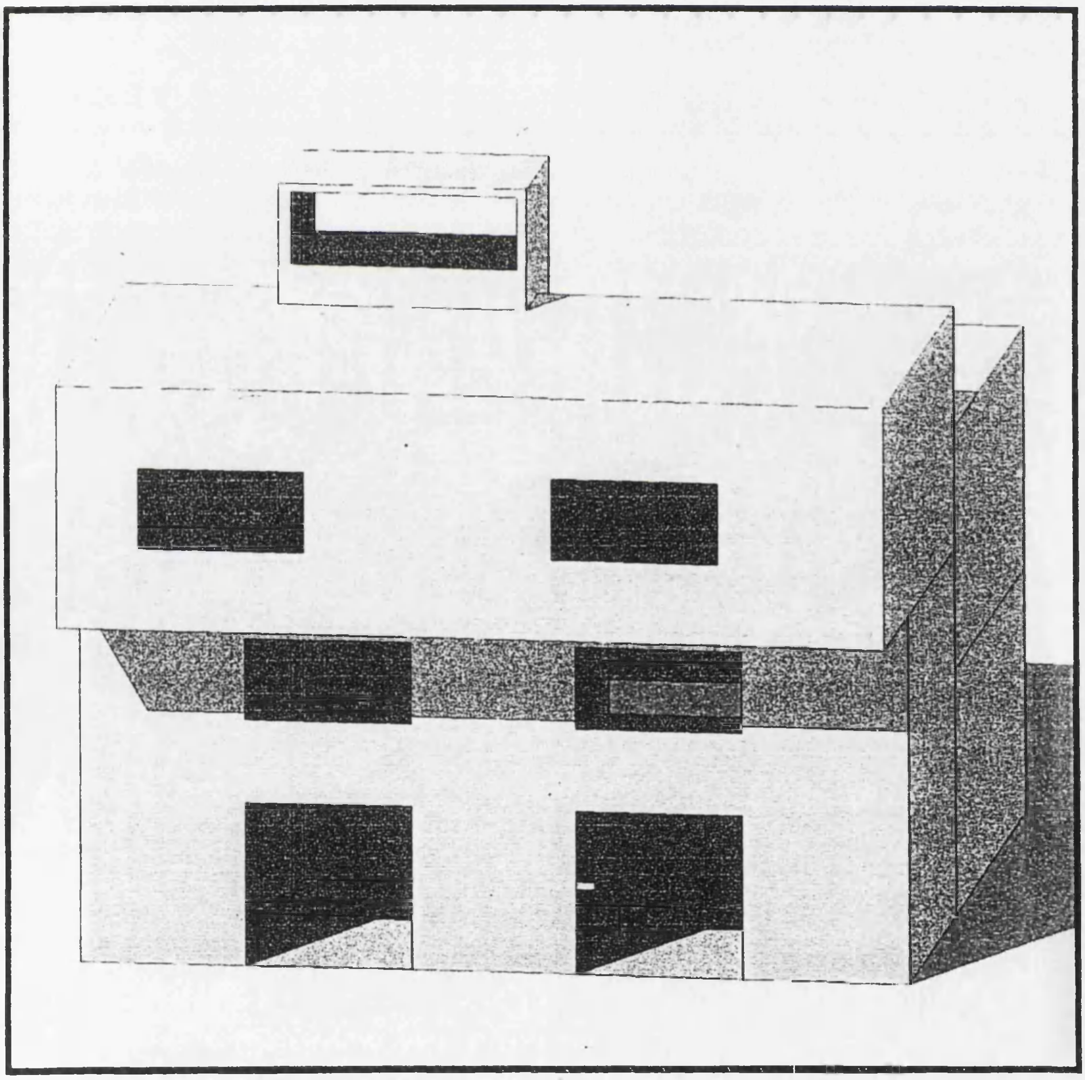


Plate (29)

Proposed model, Tripoli.

16 Jul 13:30   Eye view

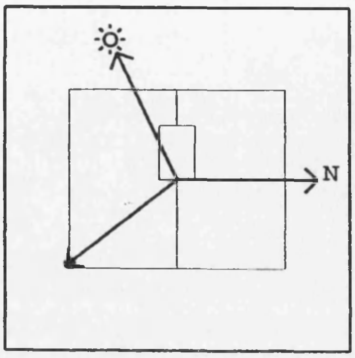
Site Latitude   = 32.50

Longitude diff. =   0.00

Model Bearing   = 270.00

Sun : azi(N) = 244.49 alt = 68.22

Eye : azi(y) = 232.00 alt = 12.00



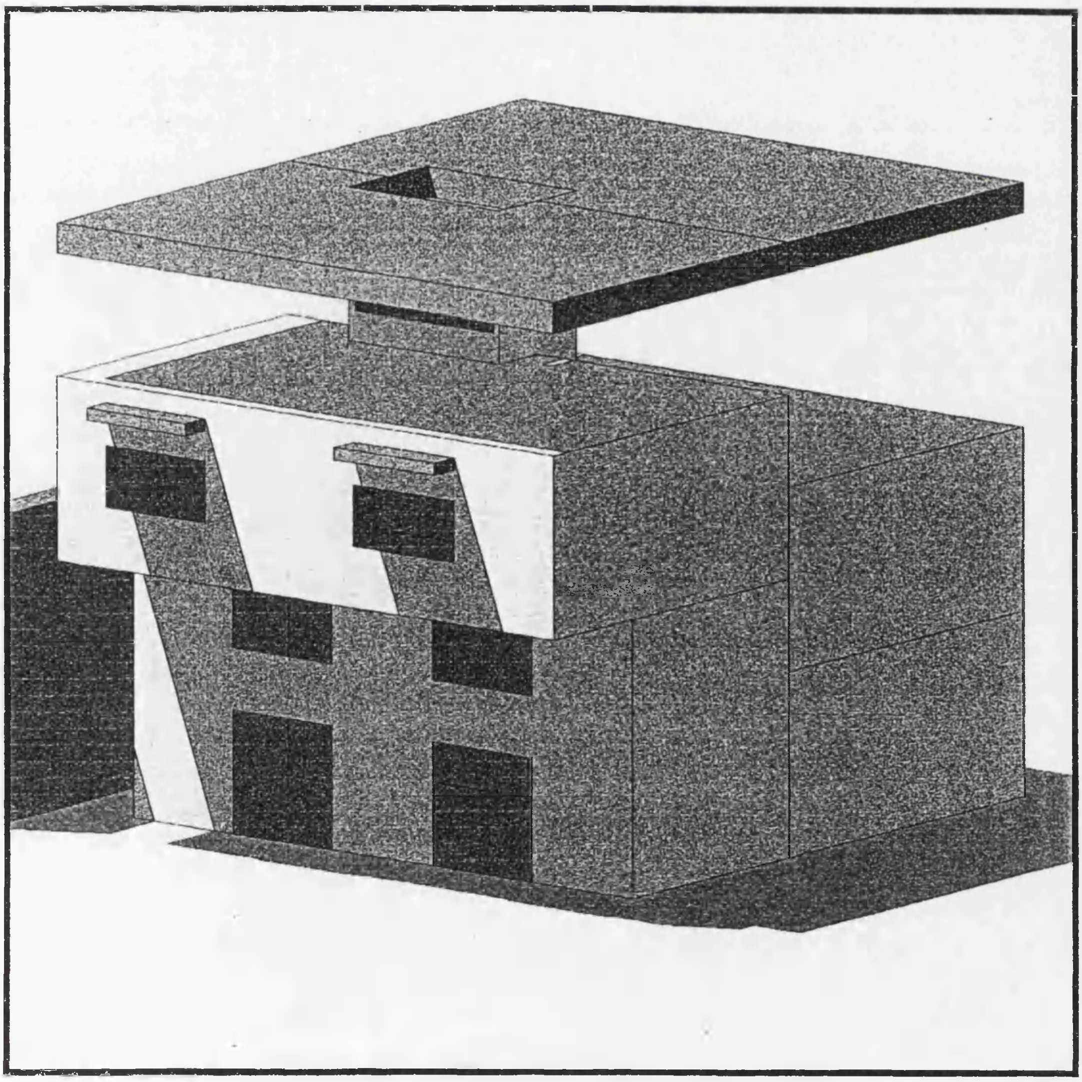


Plate (30)

b-Air infiltration and inter-zone bulk air flow

'Air' is the leakage network for a building to dynamically predict the bulk information and internal air flow between zones as a function of buoyancy and wind pressure forces.

The network is divided into two profiles one for summer and one for winter. The summer profile has two periods, the first is cross ventilation where the windows are opened , and the second period is when the underground cooling is introduced, the opening of the upper stair case window generating air flow from the earth tubes by stake effect.

Data for climate is taken for Cyprus; which has nearly the same climate as Tripoli in terms of temperature, but with slightly higher humidity.

THERMAL ANALYSIS, THE ESP+ BUILDING ENERGY SIMULATION RESULTS ANALYSIS

Analysis of the simulation result, can be read from the charts below, these can be categorised as follows

1-the result for the winter condition, Figures (49).

a-The Average internal temperature over a day, ranges from 17to20°C where the average temperature ranges between 10-24°C. This is a result of the a highly insulated envelope, which also causes the internal temperature in the middle of the day is to be lower than the external temperature.

b-Internal temperature in the first floor is higher than the lower floor as result of thermal stratification.

c-Also The south-facing rooms have significally higher temperature than the corresponding north facing rooms on each floor- e.g. living room higher than guest room, Figure (50)

d- Humidity, is indicated nearly in a steady condition, as the external RH ranges between 41% -94 % during the day (according to Cyprus). However this is not the case for Tripoli where the maximum RH loads to be lower (see chapter2). The internal RH ranges in the comfort condition between 62%-72%. The hiest values are in the guest room overnight. corresponding to the low temperature.Figure (51)

2-The result for summer conditions, Figures (52,a,b,c and d).

a- Internal temperature with the effect of the earth cooling tubes will ranged during the earth cooling period between 25°C-27°C, while the external temperature ranged between 33°C- 35°C. The living room is somwhat higher than all the other zones, at about 27oC, due to its direct connection with the stair zone, unlike the other zones which are separated by doors. However, 27oC is within the comfortable target level used in the manual calculation.

b - The results also illustrate the effectiveness of the building envelope in July, the temperature amplitude is much smaller than that outside .

c- In the afternoon , after 'switching off' the cooling system the internal temperature becomes similar to the external temperature. This because of the windows opening and the cross ventilation, and indicates that the evening /night window opening regime commences rather prematurly, say by 3hours.

d-The results also indicate the average temperatures frequencies for that month in each zone, with the most frequent internal temperature for zone 1 (living room) of 28°C, and 26°C for the other zones temperature, Figure (53).

e- ESP shows that RH will increase rapidly when windows are opened in the evening -i.e. equaling with the out side RH due to the equalination of temperatures and generous ventilation. Again a deferent of the window. opening would be an advantage. Figure (54).

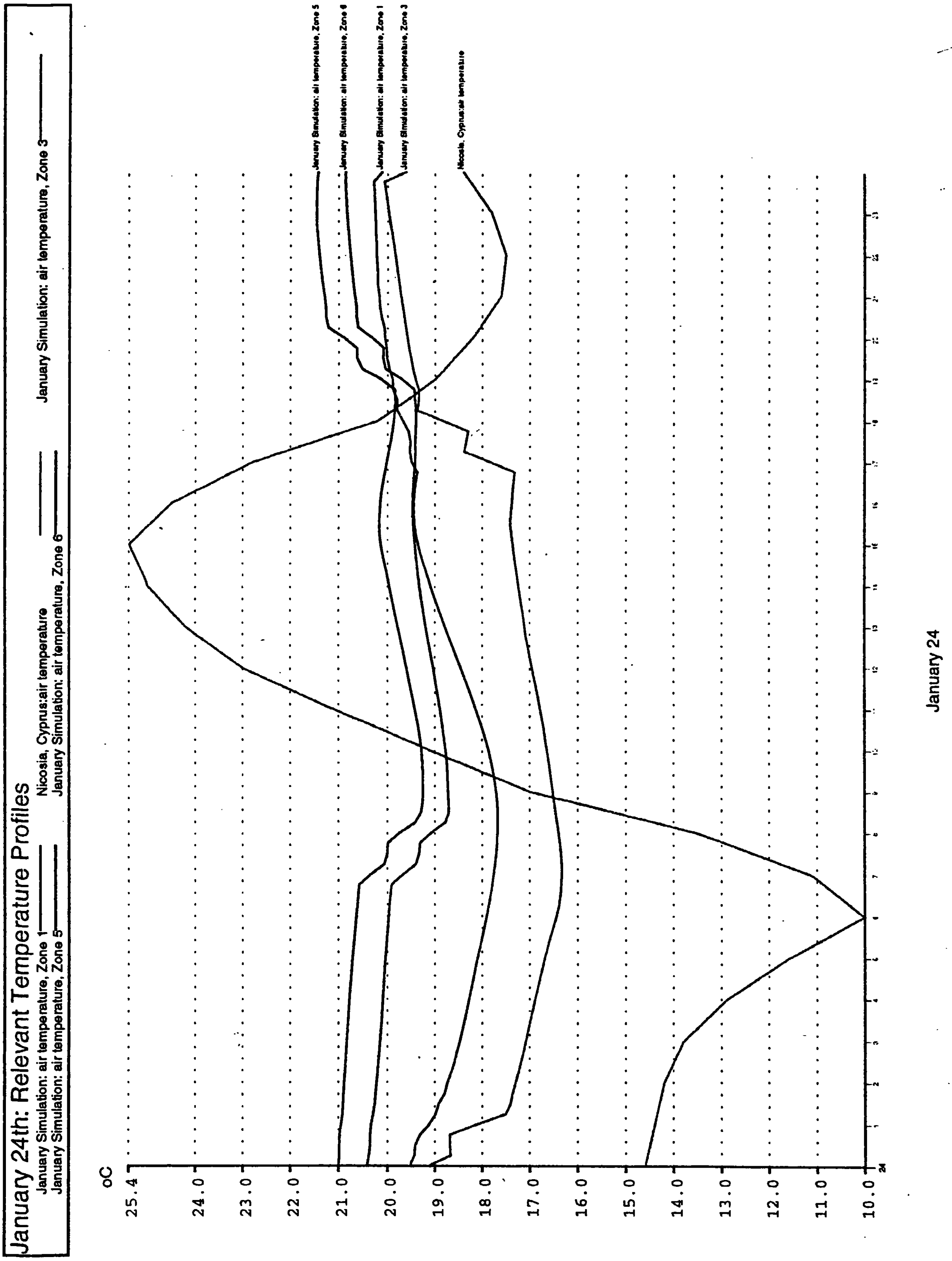
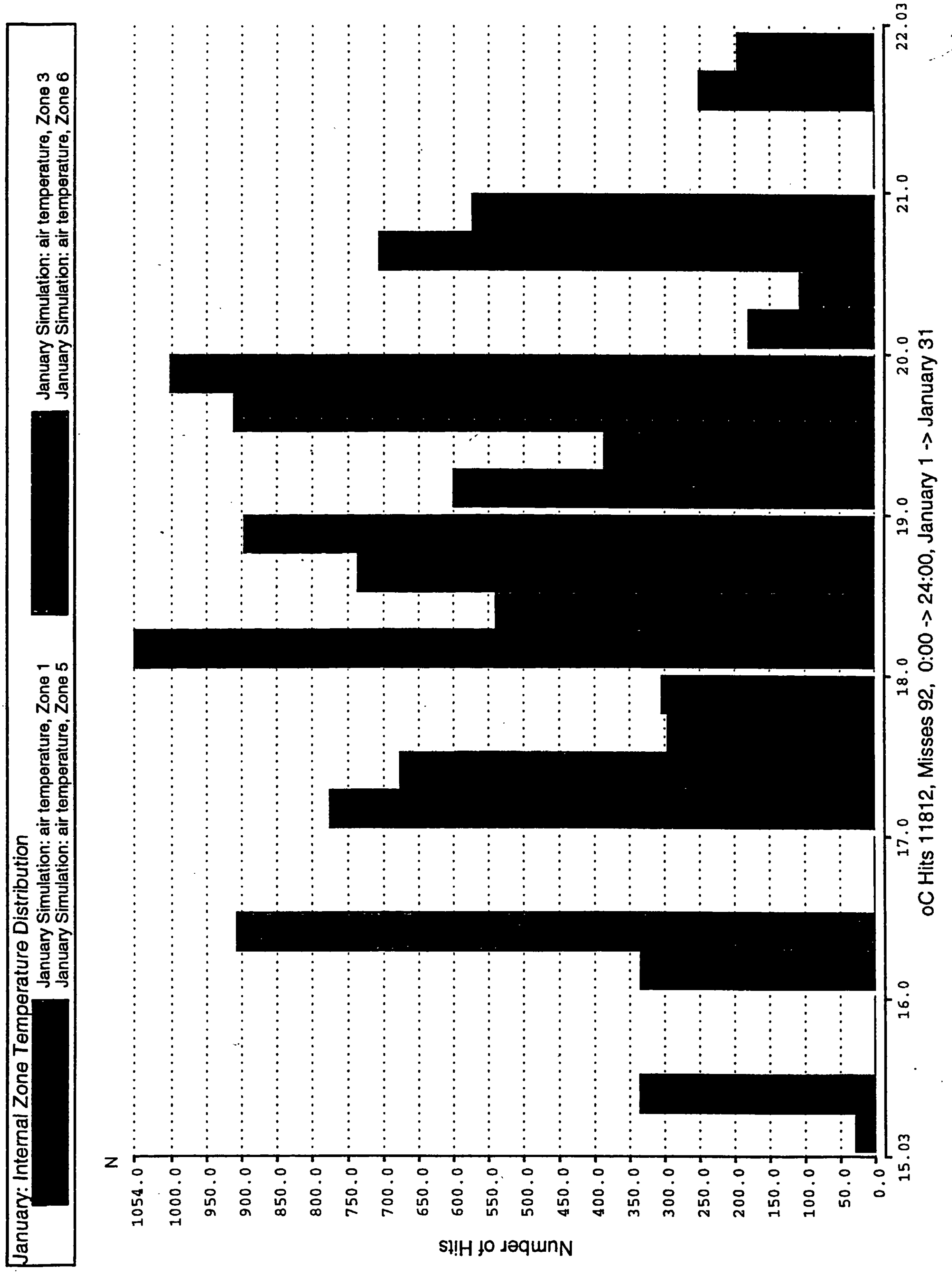
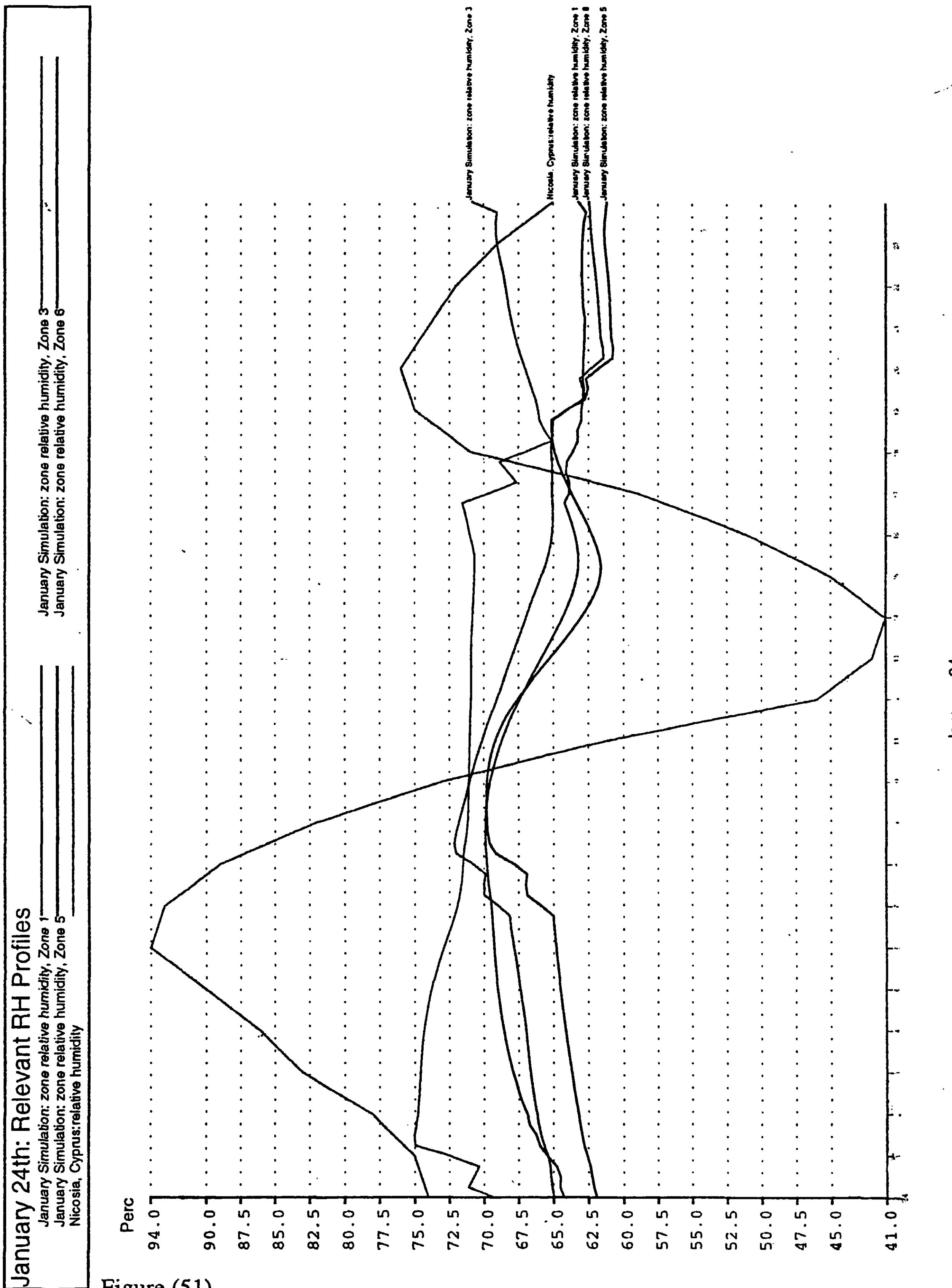

January 24th: Relevant Temperature Profiles
January Simulation: air temperature, Zone 1
January Simulation: air temperature, Zone 5
Nicosia, Cyprus:air temperature
January Simulation: air temperature, Zone 6
January Simulation: air temperature, Zone 3
oC
25.4
24.0
23.0
22.0
21.0
20.0
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
January 24

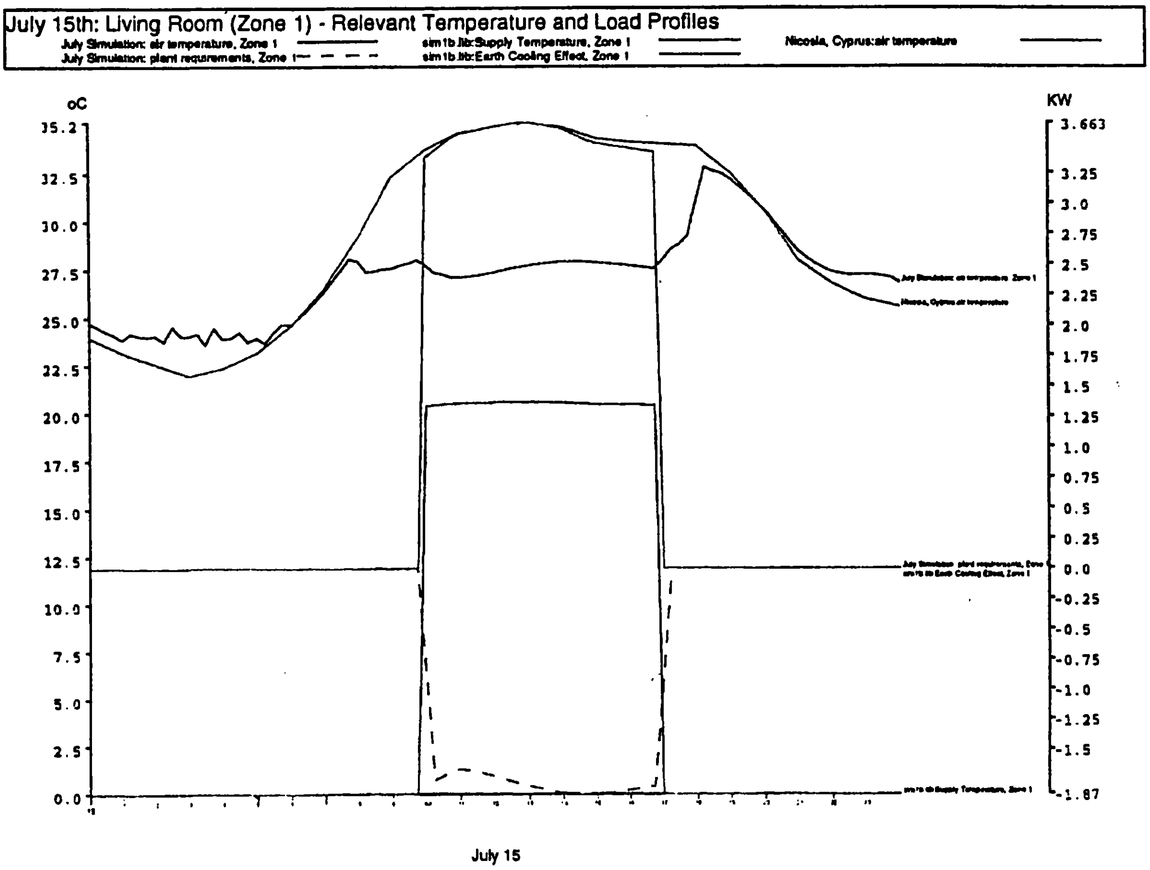
Figure (49)


January: Internal Zone Temperature Distribution
January Simulation: air temperature, Zone 1
January Simulation: air temperature, Zone 5
January Simulation: air temperature, Zone 3
January Simulation: air temperature, Zone 6
Number of Hits
N
1054.0
1000.0
950.0
900.0
850.0
800.0
750.0
700.0
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
15.03
16.0
17.0
18.0
19.0
20.0
21.0
22.03
oC Hits 11812, Misses 92, 0:00 -> 24:00, January 1 -> January 31
Figure (50)



January 24th: Relevant RH Profiles
January Simulation: zone relative humidity, Zone 1
January Simulation: zone relative humidity, Zone 5
Nicosia, Cyprus:relative humidity
January Simulation: zone relative humidity, Zone 3
January Simulation: zone relative humidity, Zone 6
Perc
94.0
90.0
87.5
85.0
82.5
80.0
77.5
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
52.5
50.0
47.5
45.0
41.0
January 24

Figure (51)


July 15th: Living Room (Zone 1) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 1
July Simulation: plant requirements, Zone 1
sim1b.lib:Supply Temperature, Zone 1
sim1b.lib:Earth Cooling Effect, Zone 1
Nicosia, Cyprus:air temperature
oC
KW
35.2
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
3.663
3.25
3.0
2.75
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.0
-1.25
-1.5
-1.87
July 15

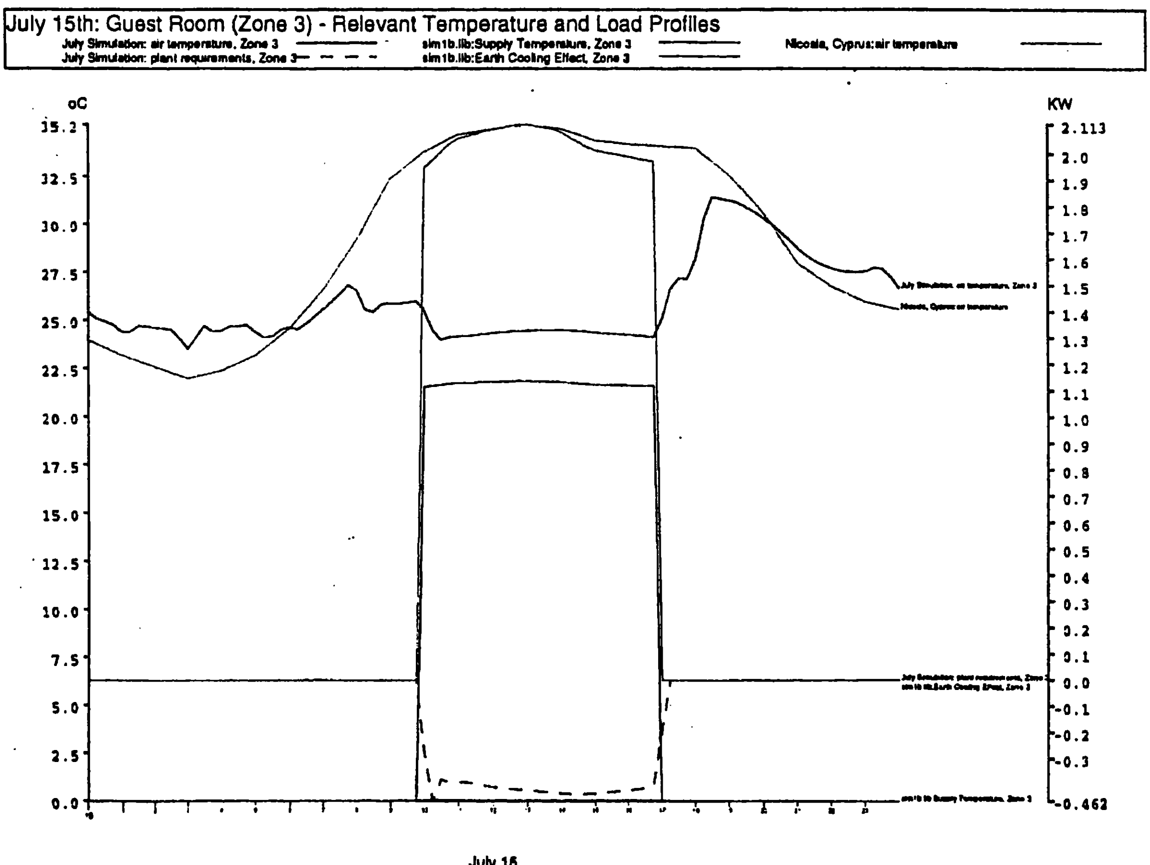
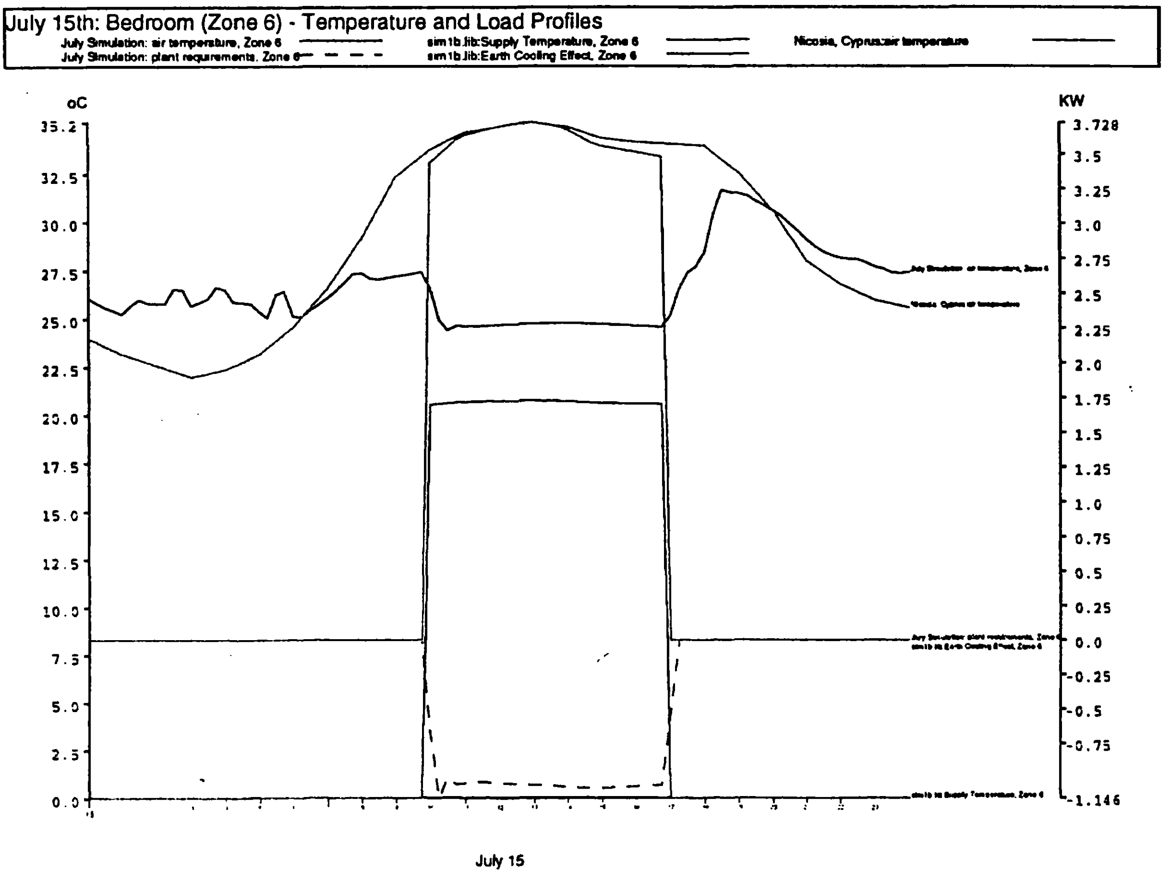

July 15th: Guest Room (Zone 3) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 3
July Simulation: plant requirements, Zone 3
sim1b.lib:Supply Temperature, Zone 3
sim1b.lib:Earth Cooling Effect, Zone 3
Nicosia, Cyprus:air temperature
oC
KW
35.2
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
2.113
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.462
July 15

Figure (52 a,b)


July 15th: Bedroom (Zone 6) - Temperature and Load Profiles
July Simulation: air temperature, Zone 6
July Simulation: plant requirements, Zone 6
sim1b.lib:Supply Temperature, Zone 6
sim1b.lib:Earth Cooling Effect, Zone 6
Nicosia, Cyprus:air temperature
oC
35.2
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
KW
3.728
3.5
3.25
3.0
2.75
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.146
July 15

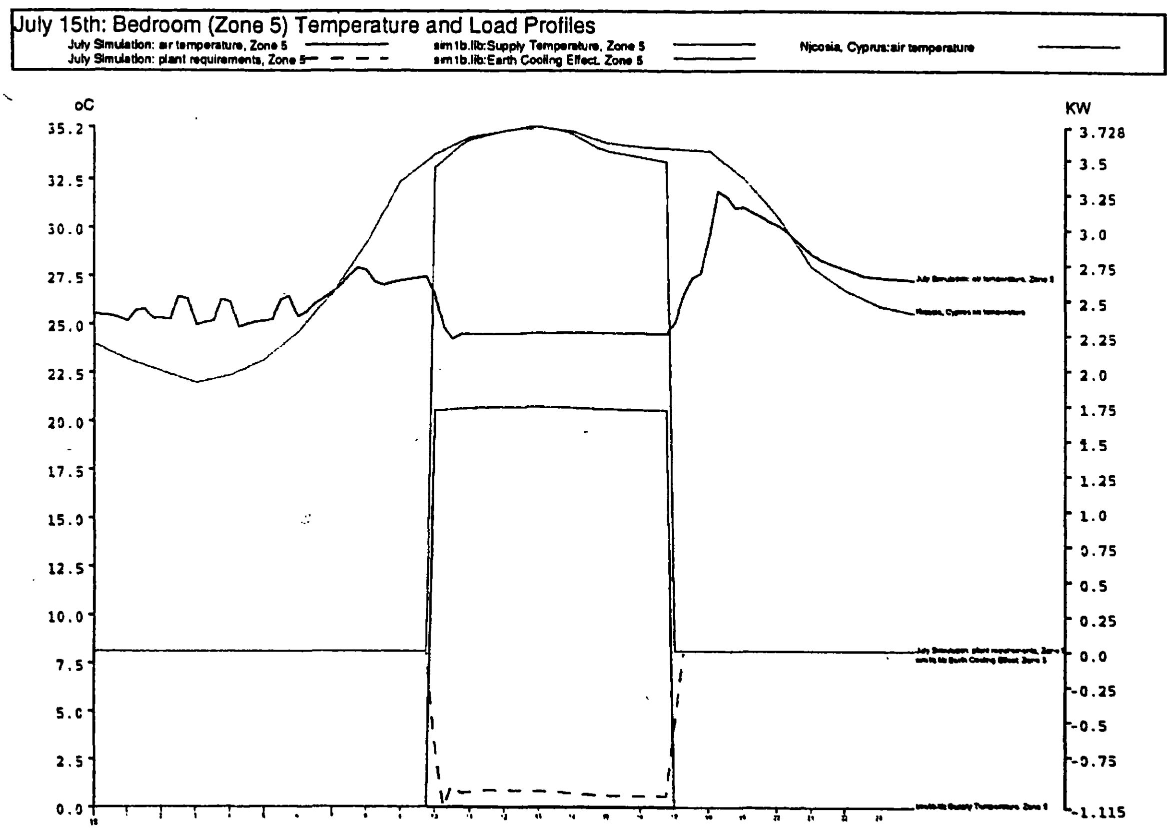

July 15th: Bedroom (Zone 5) Temperature and Load Profiles
July Simulation: air temperature, Zone 5
July Simulation: plant requirements, Zone 5
sim1b.lib:Supply Temperature, Zone 5
sim1b.lib:Earth Cooling Effect, Zone 5
Nicosia, Cyprus:air temperature
oC
35.2
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
KW
3.728
3.5
3.25
3.0
2.75
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.115
July 15

Figure (52 c,d)

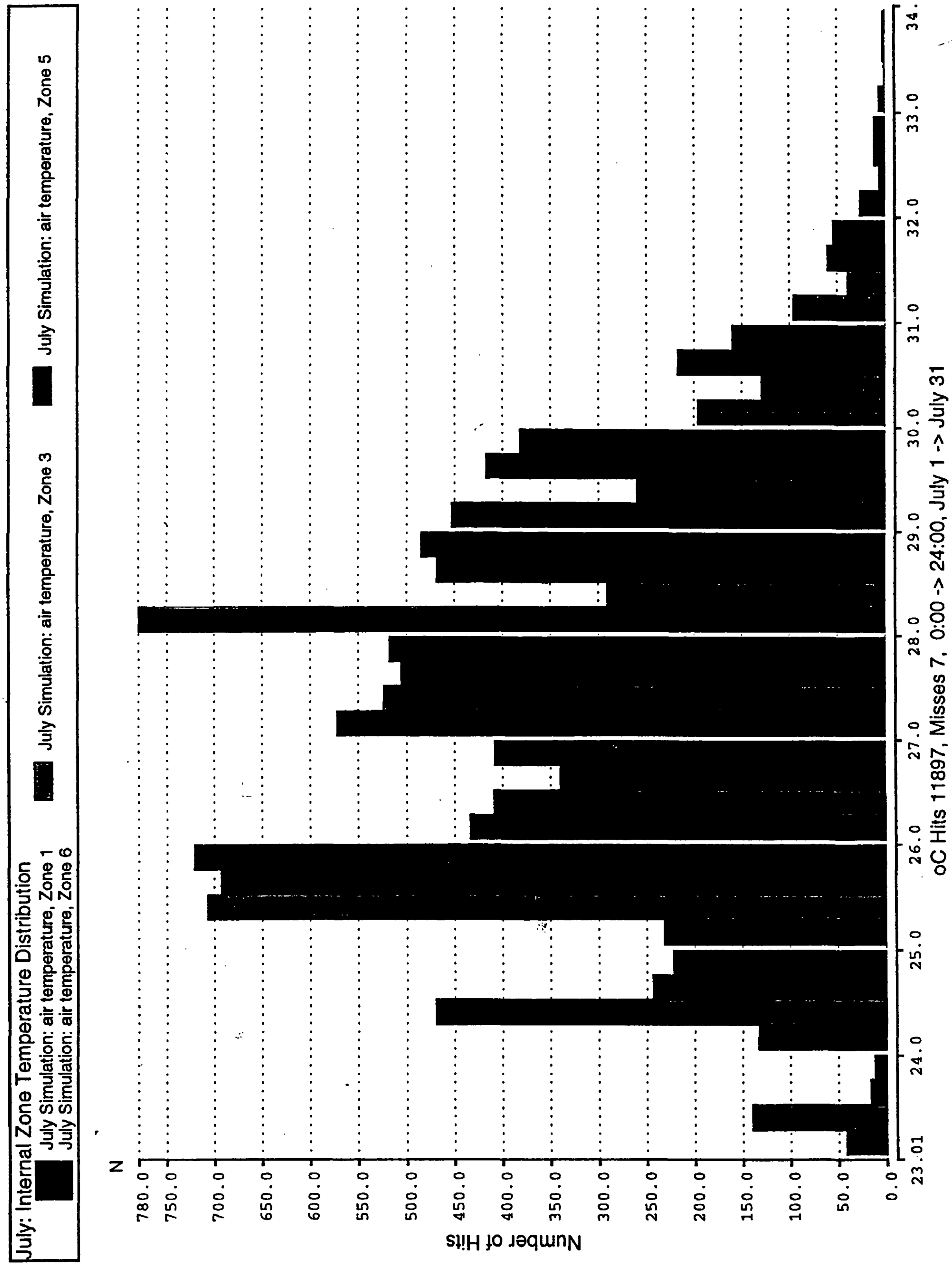

July: Internal Zone Temperature Distribution
July Simulation: air temperature, Zone 1
July Simulation: air temperature, Zone 6
July Simulation: air temperature, Zone 3
July Simulation: air temperature, Zone 5
Number of Hits
N
oC Hits 11897, Misses 7, 0:00 -> 24:00, July 1 -> July 31

Figure (53)

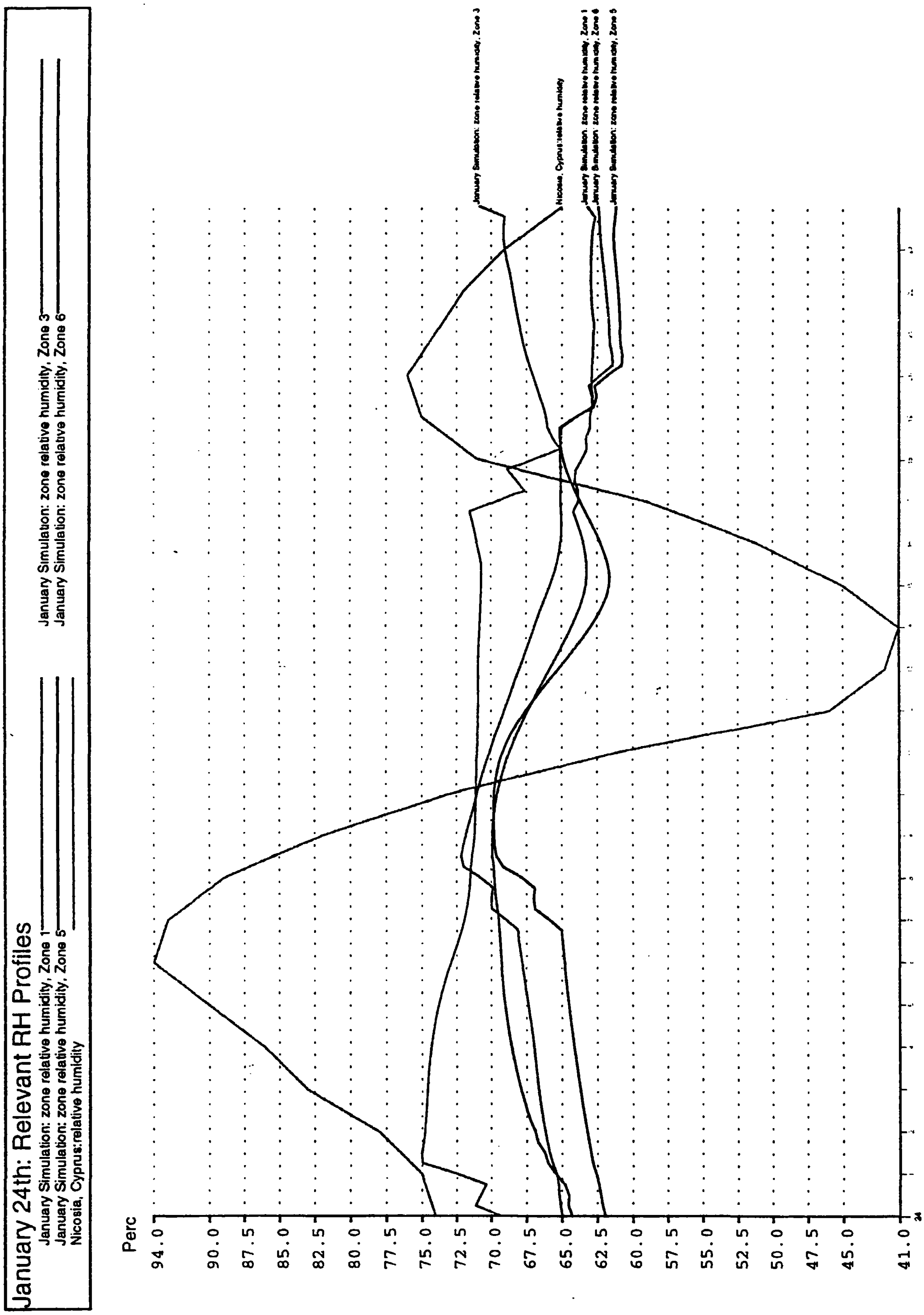

January 24th: Relevant RH Profiles
January Simulation: zone relative humidity, Zone 1
January Simulation: zone relative humidity, Zone 5
Nicosia, Cyprus:relative humidity
January Simulation: zone relative humidity, Zone 3
January Simulation: zone relative humidity, Zone 6
Perc
94.0
90.0
87.5
85.0
82.5
80.0
77.5
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
52.5
50.0
47.5
45.0
41.0
January 24

Figure (54)

CONCLUSION

From findings of the literature review together with results of the thermal analysis of the modern prototype house in Tripoli proposed in this study, it can be concluded that thermal comfort can be achieved with minimal input of auxiliary energy. The designed model also takes account of vital cultural and environmental aspects.

-The climate conscious prototype in terms of form and its orientation: The compact solution, has offered the recommended volume to surface ratio. This has reduced the exposed surface area, with two story height building providing an excellent protection for the day time room on the ground floor.

-A two room plan depth and split level section has allowed a level of cross ventilation from north to south. Height is also useful to induce thermal buoyancy, the central stairwell have an excellent aid for encouraging vertical air movement.

-South and north facing windows are preferable in summer and winter. In winter south facing windows can provide passive solar gain to meat heating load, with temperature profiles falling with the comfort range. Comfort in summer can be achieved by more complicated techniques. Earth cooling as proposed in the study has provided a high cooling load, introducing air up to 10K lower than the external temperature during daytime..

- Careful specification of the building envelope must be made, as demonstrated in the material analysis. Using a cavity wall with insulation, provides adequate damping and time lag, essential to protect indoor temperature from the extremely high external temperature during midday period..

-This study raises a question for further experiment. By using a hygroscopic material for the earth tube system, the supply air temperature is reduced compared to a non hygroscopic one, but the level of RH is still the most unknown parameter which requires experimental analysis.

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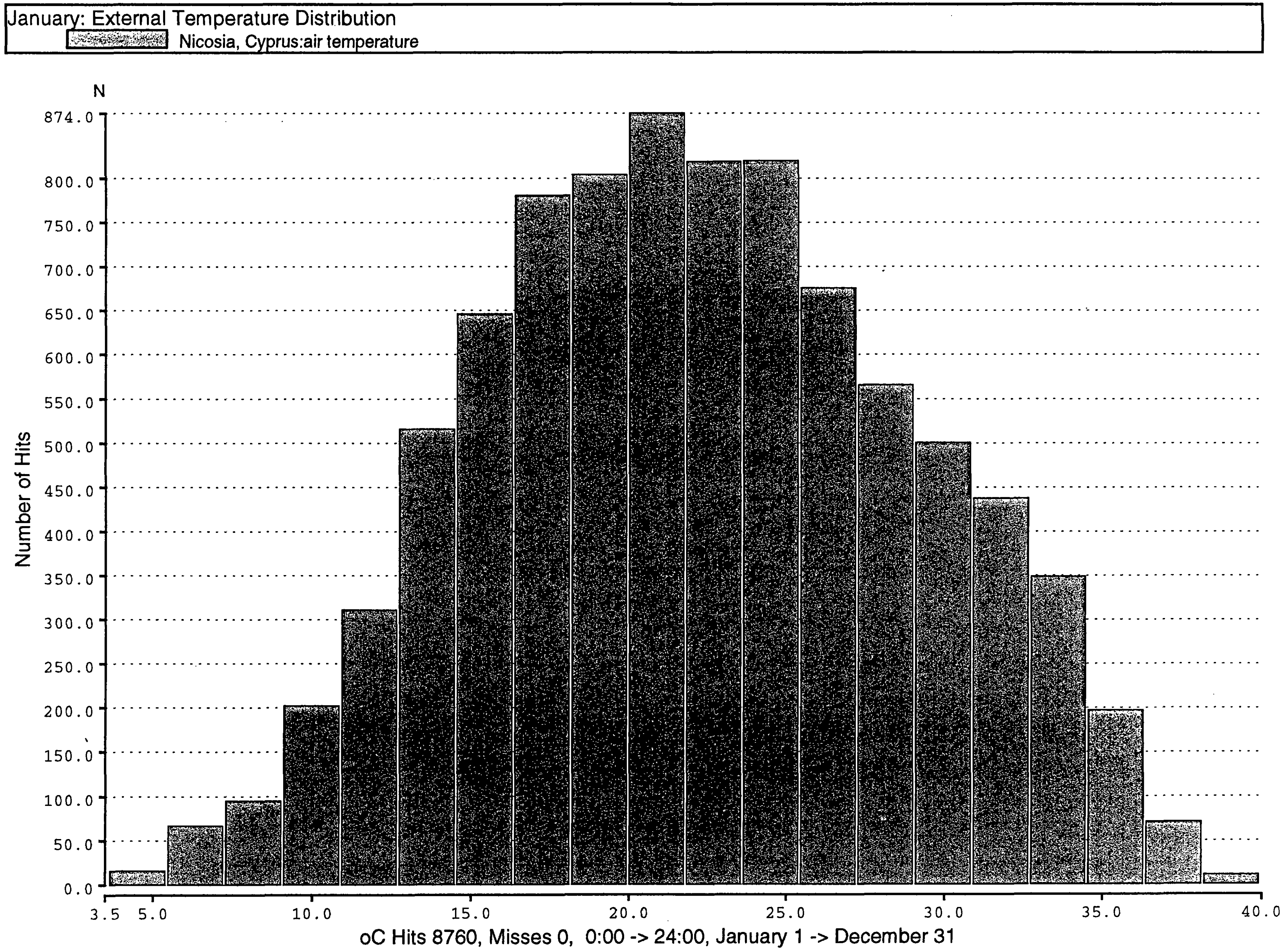
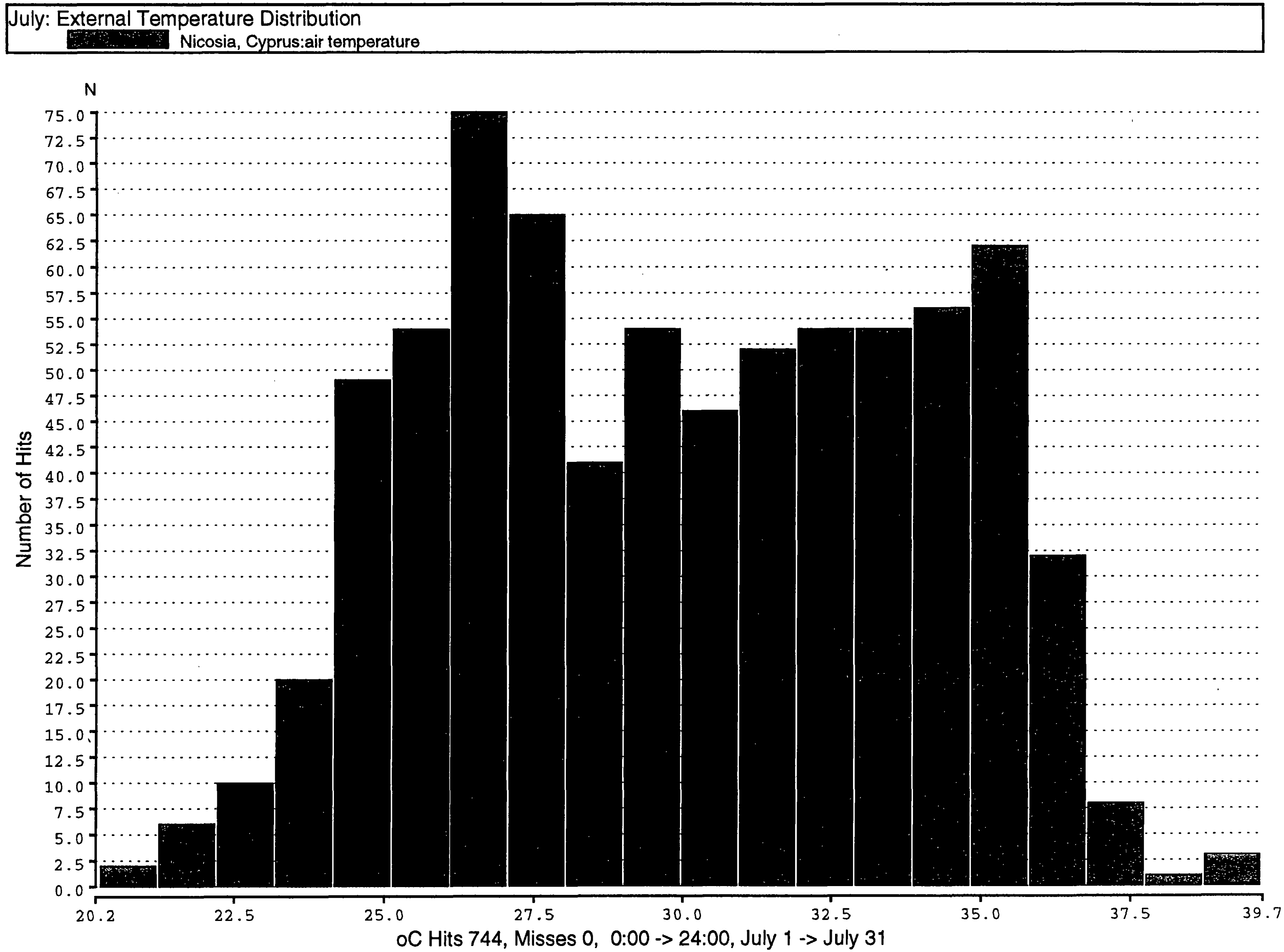
Appendix A

December	global	Hdh	HDh	Global	South	Global	Global	East	Global	West	Hdhs	
	Horizintal	diffuse	direct	South	direct	North	East	direct	West	direct	V. deffuse	
7	0	0	0	0	0	0	0	0	0	0	0	
8	0.1057	0.053	0.053	0.184	0.1672	0.037	0.09317	0.0561	0.037	0	0.0265	
9	0.2175	0.101	0.116	0.28	0.232	0.072	0.17084	0.09858	0.072	0	0.0505	
10	0.316	0.138	0.178	0.381	0.299	0.1006	0.2222	0.1216	0.1006	0	0.069	
11	0.385	0.16	0.225	0.45	0.34234	0.119	0.19749	0.07899	0.119	0	0.08	
12	0.4	0.178	0.226	0.46	0.35	0.129	0.129	0	0.129	0	0.089	
13	0.385	0.16	0.225	0.45	0.34234	0.119	0.119	0	0.19749	0.07899	0.08	
14	0.316	0.138	0.178	0.381	0.299	0.1006	0.1006	0	0.2222	0.1216	0.069	
15	0.2175	0.101	0.116	0.28	0.232	0.072	0.072	0	0.17084	0.09858	0.0505	
16	0.1057	0.053	0.053	0.184	0.1672	0.037	0.037	0	0.09317	0.0561	0.0265	
17	0	0	0	0	0	0	0	0	0	0	0	
June	global	diffuse	direct	Global	south	Global	north	global	east	Global	west	V.diffuse
	Horizontal	Hdh	HDh	South	direct	North	direct	East	direct	West	direct	
6	0.12104	0.05381	0.06723	0.039	0	0.152	0.113	0.306	0.267	0.039	0	0.0269
7	0.267712	0.10234	0.16537	0.078	0	0.157	0.079	0.425	0.348	0.077	0	0.0512
8	0.4628	0.14665	0.31615	0.119	0	0.153	0.0338	0.5366	0.417	0.119	0	0.0733
9	0.6408	0.184625	0.456175	0.156	0	0.156	0	0.156393	0	0.156	0	0.0923
10	0.7547	0.27958	0.47512	0.256	0.0409	0.215	0	0.215	0	0.215	0	0.1398
11	0.833	0.29751	0.53549	0.306	0.0737	0.232	0	0.232	0	0.232	0	0.1488
12	0.9398	0.3376	0.6022	0.347	0.0849	0.263	0	0.263	0	0.263	0	0.1688
13	0.833	0.29751	0.53549	0.306	0.0737	0.232	0	0.232	0	0.232	0	0.1488
14	0.7547	0.27958	0.4751	0.256	0.0409	0.215	0	0.215	0	0.215	0	0.1398
15	0.6408	0.184625	0.456175	0.156	0	0.156	0	0.156	0	0.156	0	0.09231
16	0.4628	0.14665	0.31615	0.119	0	0.153	0.0338	0.119	0	0.5366	0.417	0.0733
17	0.267712	0.10234	0.16537	0.078	0	0.157	0.079	0.077	0	0.425	0.348	0.0511
18	0.12104	0.05381	0.06723	0.039	0	0.152	0.113	0.039	0	0.306	0.267	0.0269

Tripoli climate data	JAN	FEB	MAR	APR	MAY	JUN	NULY	AUG	SEP	OCT	NOV	DEC	aNNUAL	
Relative humidity%	50	55	50	58	61	66	67	74	65	60	51	47	61	
Ave Max %	43	65	52	58	57	68	79	75	68	67	55	43		
Ave Min %	52	48	66	49	49	64	68	64	55	62	45	48		
wind velocityM/S	3.088						2.5							
WIND DIRECTION	west						northeast							
Vapour pressur mbs	9	10	11	12	13	16	21	20	18	15	14	12		
Evapouration cm	5	7	7	8	9	9	10	11	8	7	7	6	7	
sunshin hours	158	172	186	225	260	285	344	335	243	214	162	146	2730	
sunrise-sunset	10	11	12	13	13	14	13	13	12	11	10	10		
monthly mean daily														
global kwh/m^2	2.918	3.492	4.594	5.451	6.5248	7.11	8.06	7.383	5.72	6.037	3.021	2.484		
diffuse	0.4134	0.393	0.389	0.362	0.3088	0.28	0.155	0.167	0.2866	0.309	0.39	0.444		
direct	2.5046	3.099	4.205	5.089	6.216	6.83	7.905	7.216	5.4334	5.728	2.631	2.04		
Temper														
daily average	12	13	16	19	22	25	28	27	26	22	16	13	20	
Ave.Max	21	23	29	30	32	34	35	34	33	31	29	23	41	
Ave Min	4	6	7	9	12	15	18	19	18	14	9	6	4	
Diuranl range Temp	17	17	22	21	20	19	17	15	15	17	20	17	37	

month	**TEMP C**											
TIME hour	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
0	10	10	11.75	15.2	23.25	25.05	25.04	22.36	17.81	13.03	14.15	8.25
1	9.26	10.25	11.25	14.25	22.44	24.27	24.26	21.59	17.1	12.44	12.75	7.75
2	8.2	9.25	10.75	13.25	21.86	23.71	23.68	21.03	16.58	12.01	11.75	7.25
3	7.34	8.75	10.25	12	21.51	23.37	23.24	20.69	16.26	11.74	10.5	6.75
4	6.54	8.25	9.75	11.5	21.39	23.25	23.22	20.58	16.16	11.66	9.75	5.75
5	6.12	7.75	9.25	10.5	23.7	25.49	25.48	22.79	18.22	13.37	9.25	4.25
6	6.8	9.25	10.25	12.75	25.97	27.68	26.94	24.96	23.24	15.04	9.75	5.25
7	8.2	10.5	11.5	14.2	28.14	29.78	29.82	27.04	22.17	16.64	11.25	7.75
8	9.75	11.75	13.25	15.25	30.18	31.75	31.81	28.99	23.98	18.15	12.25	8.75
9	11.55	13.25	15	18.25	32.04	33.54	33.62	30.77	25.64	19.52	14.25	10.25
10	12.45	15.25	17.25	19.75	33.68	35.12	35.22	32.34	27.1	20.73	16.25	11.75
11	14.25	16.5	18.75	21.75	35.07	36.47	36.58	33.67	28.34	21.76	19.25	12.75
12	15.8	18.25	20.25	23.75	36.18	37.54	37.67	34.73	29.33	22.58	20.25	14.25
13	17.6	19.75	21.75	25.25	36.99	38.32	38.46	35.51	30.05	23.18	22	15.25
14	18.2	20.75	23.25	26.25	37.48	38.8	38.94	35.98	30.49	23.54	22.75	16.25
15	18.65	21.5	24.5	26.75	37.65	38.96	39.1	36.14	30.64	23.66	23.75	17.25
16	18.2	21.25	24.25	26.25	35.69	37.07	37.19	34.27	28.89	22.22	23.25	16.5
17	17.75	20.5	23.5	25.5	33.76	35.2	35.3	32.42	27.17	20.79	23	15.75
18	16.45	19.5	22.5	24.25	31.88	33.39	33.47	30.62	25.5	19.41	22.75	15
19	15.75	18.75	21.5	22.5	30.09	31.66	31.72	28.91	23.91	18.08	21.25	14.25
20	14.25	17.75	19.25	21.25	28.41	30.04	30.08	27.3	22.41	16.84	20.75	12.25
21	12.5	16.5	18.25	19.25	26.87	28.54	28.57	25.82	21.03	15.7	19.25	11.5
22	11.75	14.75	16.25	17.5	25.48	27.2	27.22	24.49	19.8	14.68	17.25	9.75
23	10.25	12.25	12.75	15.25	24.27	26.03	26.03	23.33	18.72	13.78	14.5	8.25

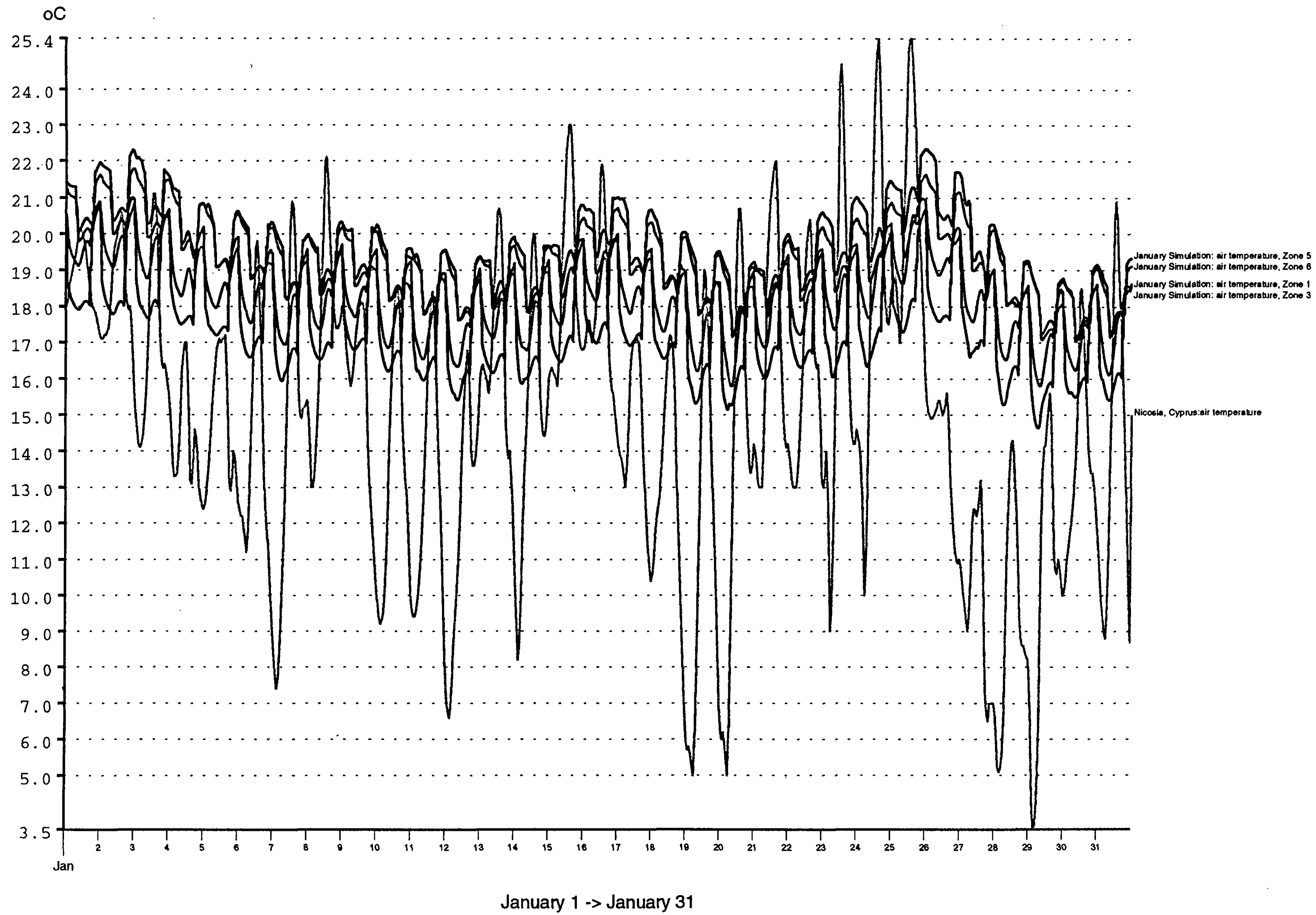

January: External Temperature Distribution
Nicosia, Cyprus:air temperature
N
874.0
800.0
750.0
700.0
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Number of Hits
3.5
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
oC Hits 8760, Misses 0, 0:00 -> 24:00, January 1 -> December 31

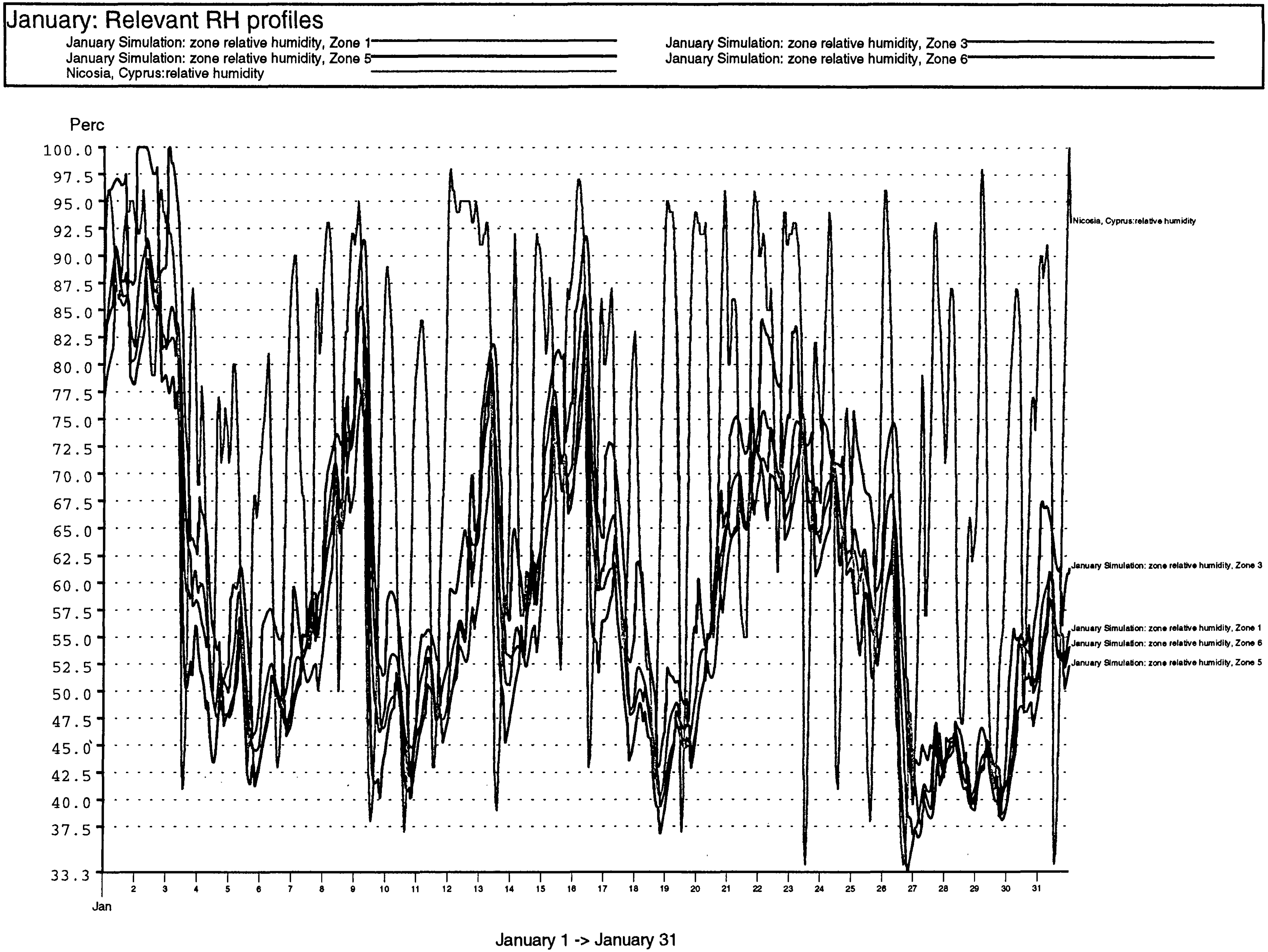


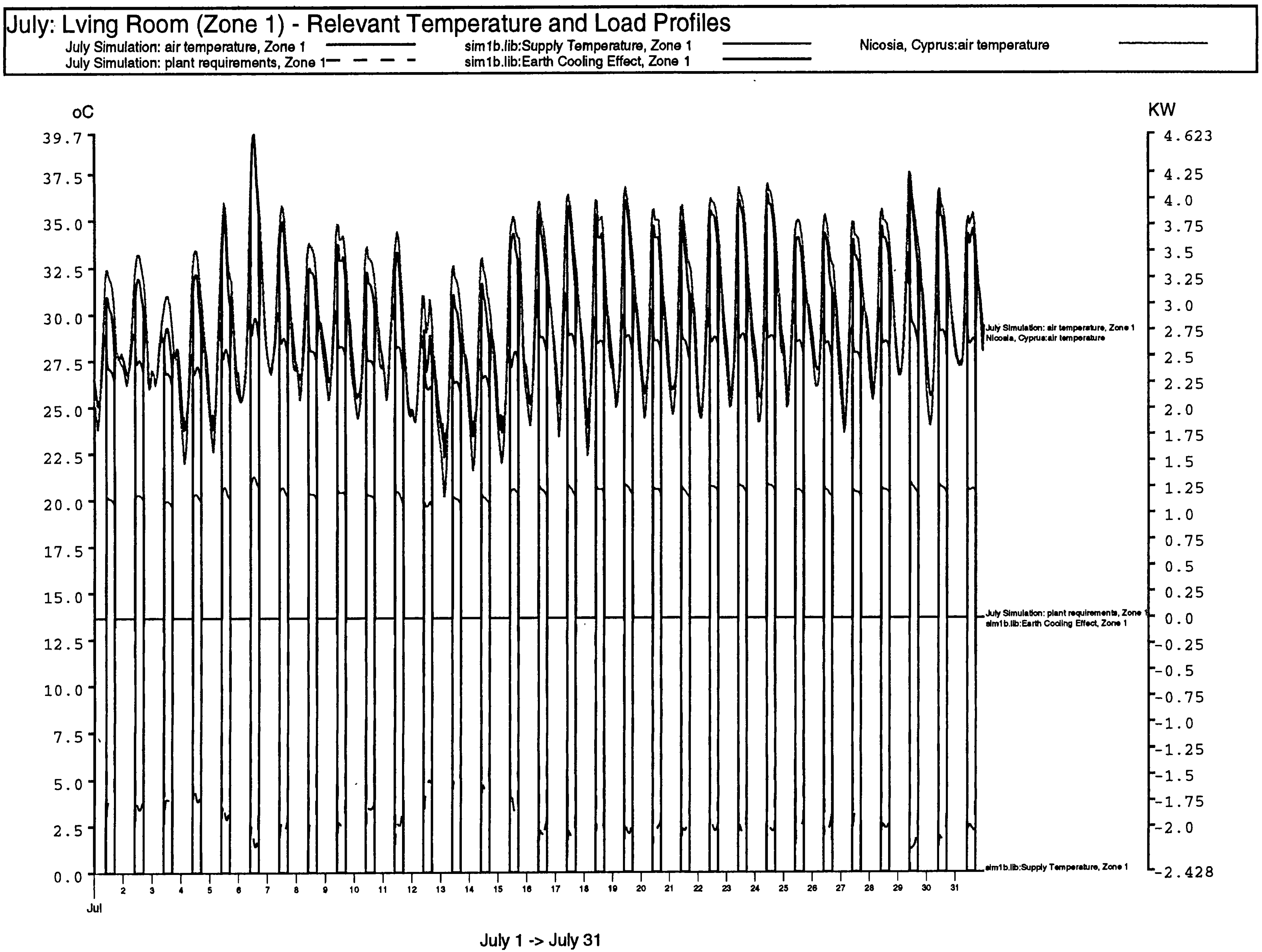
July: External Temperature Distribution
Nicosia, Cyprus:air temperature
N
Number of Hits
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
20.2
22.5
25.0
27.5
30.0
32.5
35.0
37.5
39.7
oC Hits 744, Misses 0, 0:00 -> 24:00, July 1 -> July 31

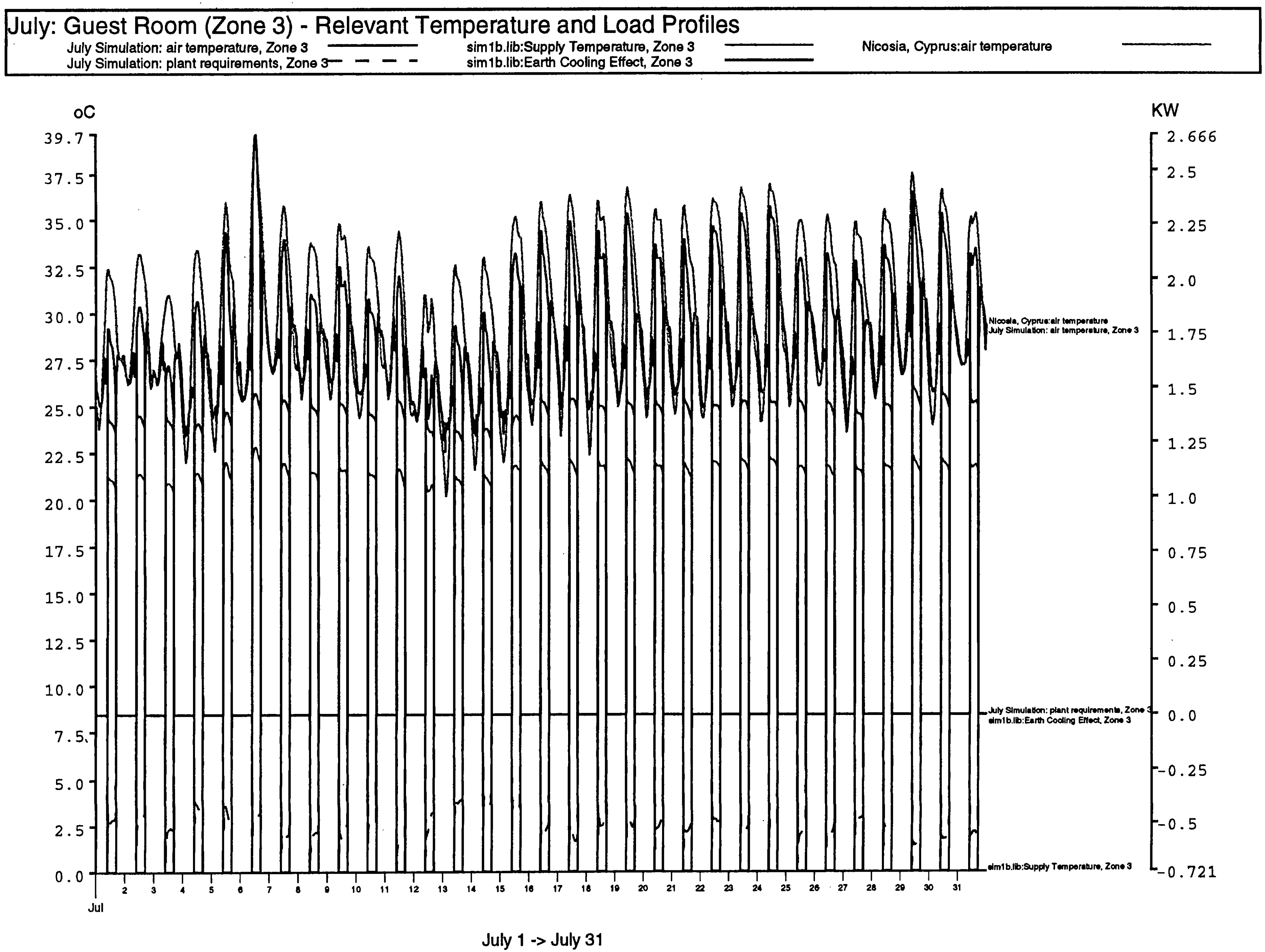
January: Relevant Temperature Profiles

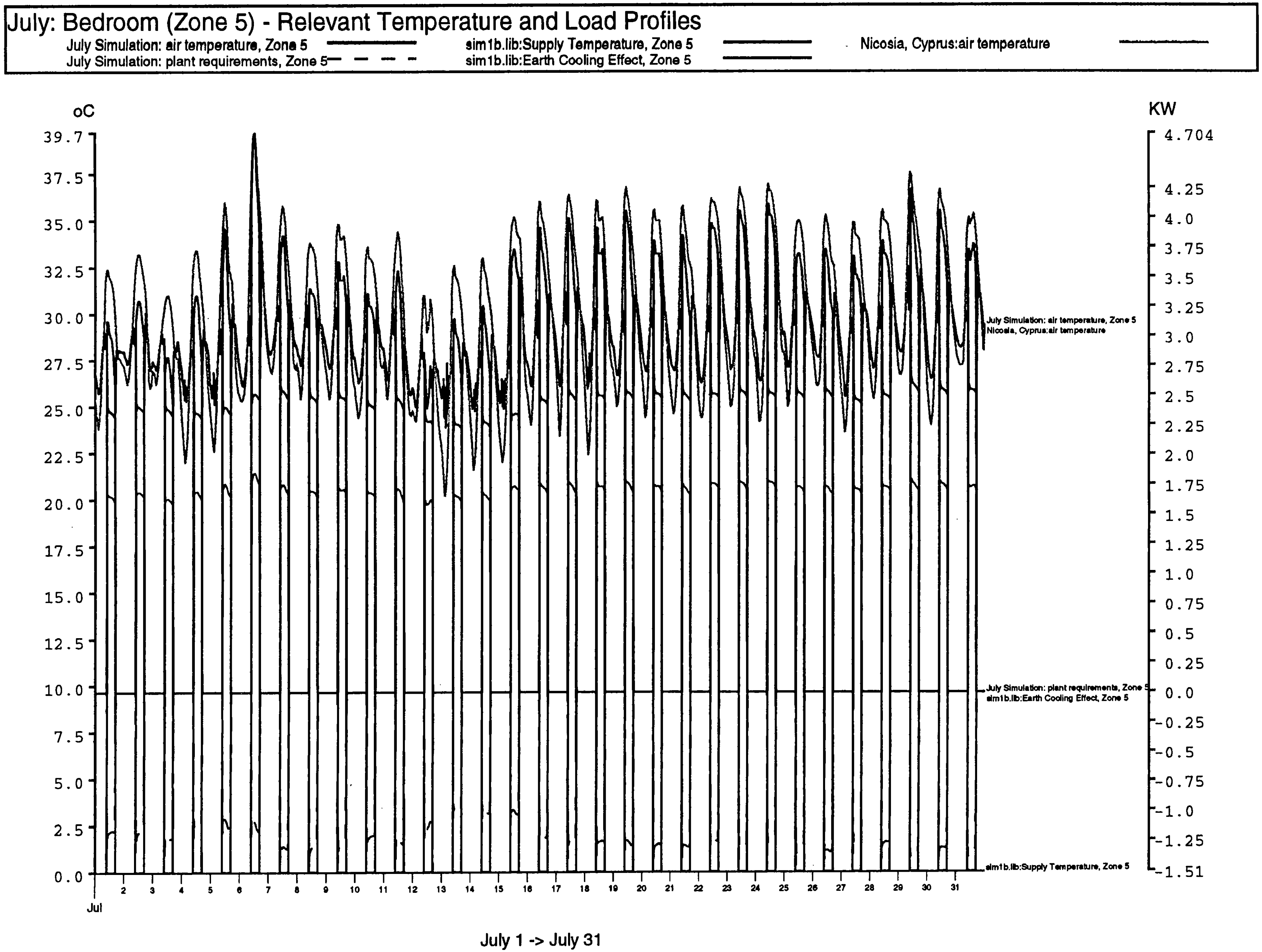
January Simulation: air temperature, Zone 1 — Nicosia, Cyprus:air temperature — January Simulation: air temperature, Zone 3
January Simulation: air temperature, Zone 5 — January Simulation: air temperature, Zone 6

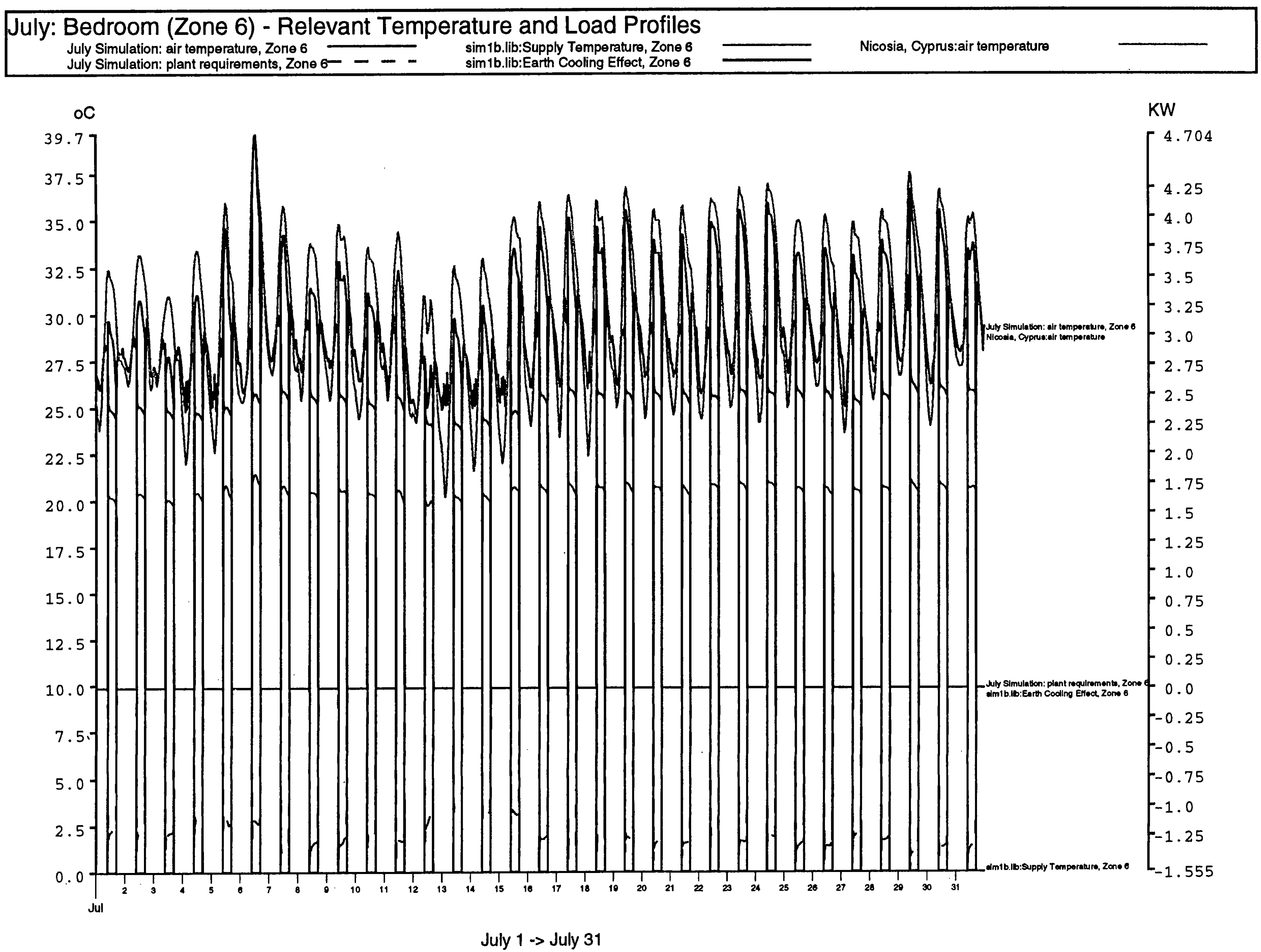


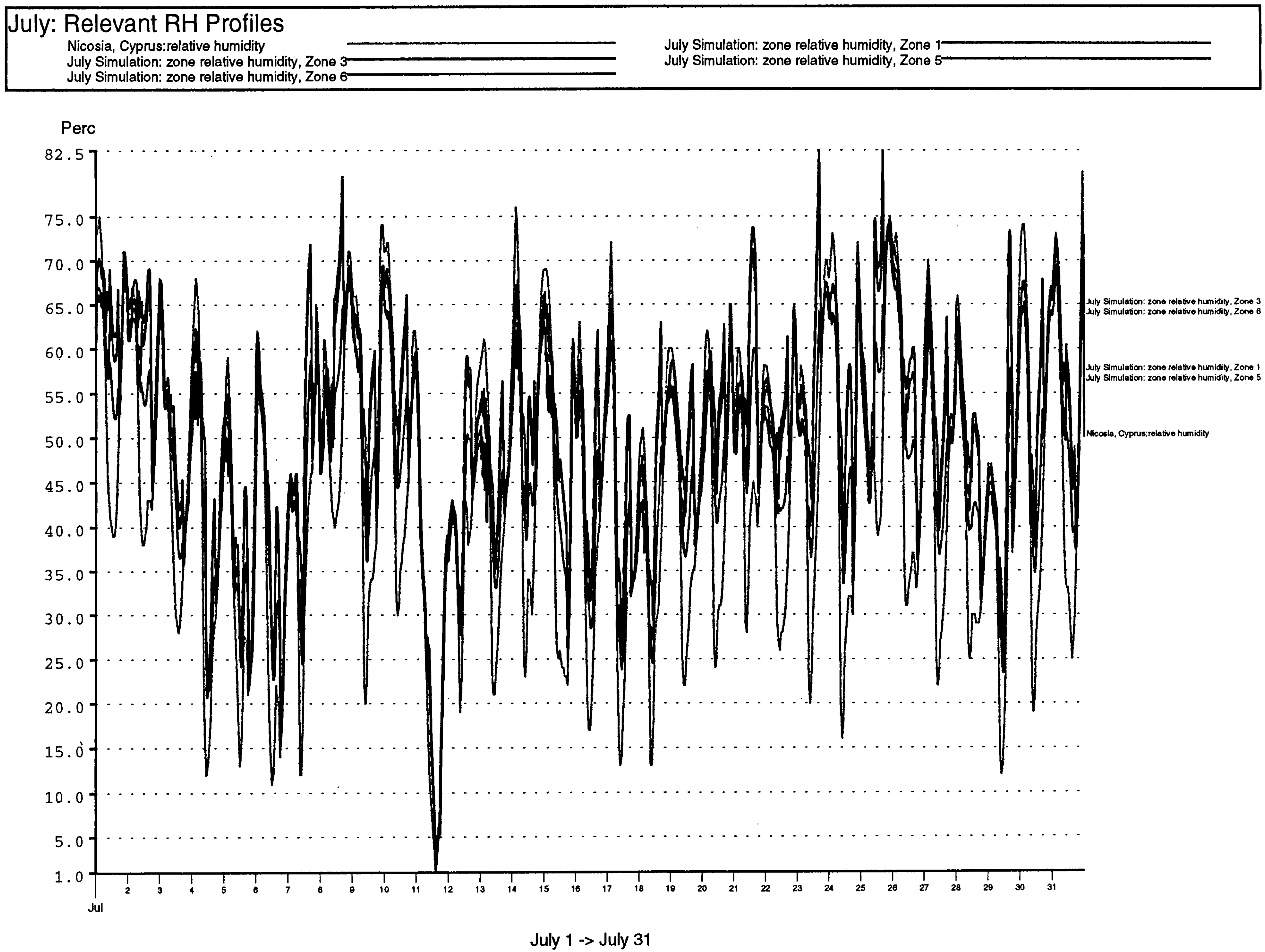

January: Relevant RH profiles
January Simulation: zone relative humidity, Zone 1
January Simulation: zone relative humidity, Zone 3
January Simulation: zone relative humidity, Zone 5
January Simulation: zone relative humidity, Zone 6
Nicosia, Cyprus:relative humidity
Perc
100.0
97.5
95.0
92.5
90.0
87.5
85.0
82.5
80.0
77.5
75.0
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
52.5
50.0
47.5
45.0
42.5
40.0
37.5
33.3
Jan
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Nicosia, Cyprus:relative humidity
January Simulation: zone relative humidity, Zone 3
January Simulation: zone relative humidity, Zone 1
January Simulation: zone relative humidity, Zone 6
January Simulation: zone relative humidity, Zone 5
January 1 -> January 31


July: Lving Room (Zone 1) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 1
July Simulation: plant requirements, Zone 1
sim1b.lib:Supply Temperature, Zone 1
sim1b.lib:Earth Cooling Effect, Zone 1
Nicosia, Cyprus:air temperature
oC
KW
39.7
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
4.623
4.25
4.0
3.75
3.5
3.25
3.0
2.75
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.0
-1.25
-1.5
-1.75
-2.0
-2.428
Jul
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
July 1 -> July 31


July: Guest Room (Zone 3) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 3
July Simulation: plant requirements, Zone 3
sim1b.lib:Supply Temperature, Zone 3
sim1b.lib:Earth Cooling Effect, Zone 3
Nicosia, Cyprus:air temperature
oC
39.7
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
KW
2.666
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.721
Jul
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
July 1 -> July 31


July: Bedroom (Zone 5) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 5
July Simulation: plant requirements, Zone 5
sim1b.lib:Supply Temperature, Zone 5
sim1b.lib:Earth Cooling Effect, Zone 5
Nicosia, Cyprus:air temperature
oC
KW
Jul
July 1 -> July 31

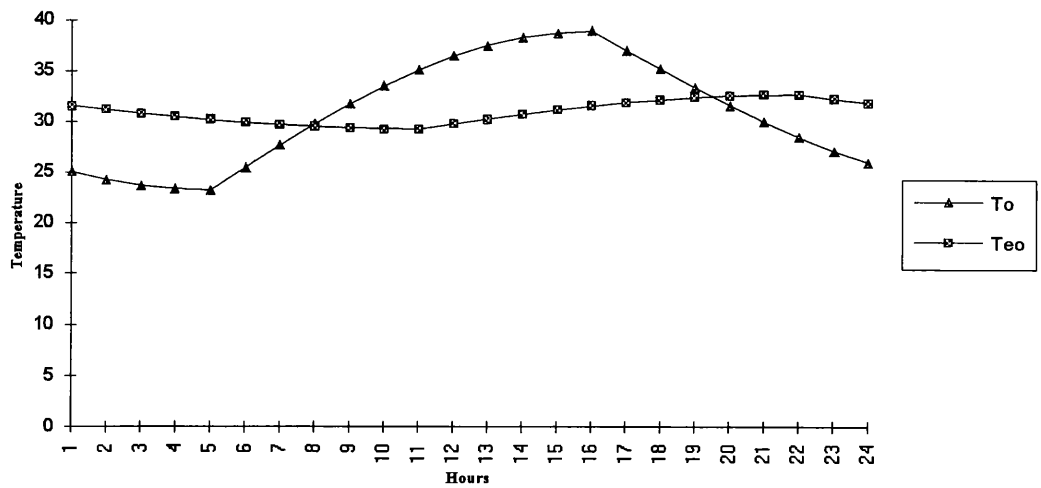

July: Bedroom (Zone 6) - Relevant Temperature and Load Profiles
July Simulation: air temperature, Zone 6
July Simulation: plant requirements, Zone 6
sim1b.lib:Supply Temperature, Zone 6
sim1b.lib:Earth Cooling Effect, Zone 6
Nicosia, Cyprus:air temperature
oC
39.7
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
KW
4.704
4.25
4.0
3.75
3.5
3.25
3.0
2.75
2.5
2.25
2.0
1.75
1.5
1.25
1.0
0.75
0.5
0.25
0.0
-0.25
-0.5
-0.75
-1.0
-1.25
-1.555
Jul
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
July 1 -> July 31



July: Relevant RH Profiles
Nicosia, Cyprus:relative humidity
July Simulation: zone relative humidity, Zone 3
July Simulation: zone relative humidity, Zone 6
July Simulation: zone relative humidity, Zone 1
July Simulation: zone relative humidity, Zone 5
Perc
82.5
75.0
70.0
65.0
60.0
55.0
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
1.0
Jul
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
July 1 -> July 31

Appendix B

Hollow Concrete Block Wall

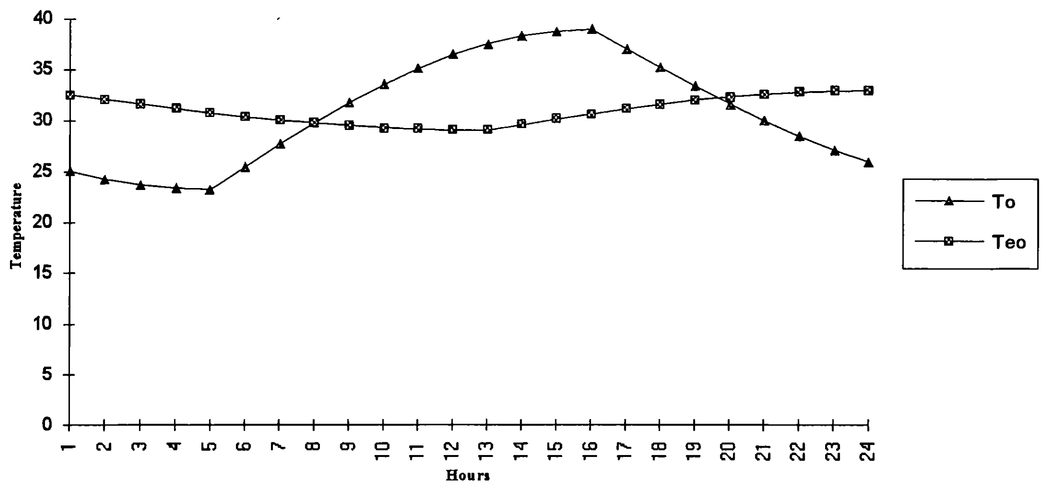


Thermal Properties

U-Value =	0.58 W/m2 C
Admittance	Y= 3.09
Decrement factor	f = 0.45
Surface factor	F= 0.78
Time Lag	Φ = 5.19 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Hollow Concrete block	0.1	0.38	1200	653	30
3	Plaster, Dense	0.02	0.5	1300	1000	80

Hollow Concrete block with insulation (polyurethane).

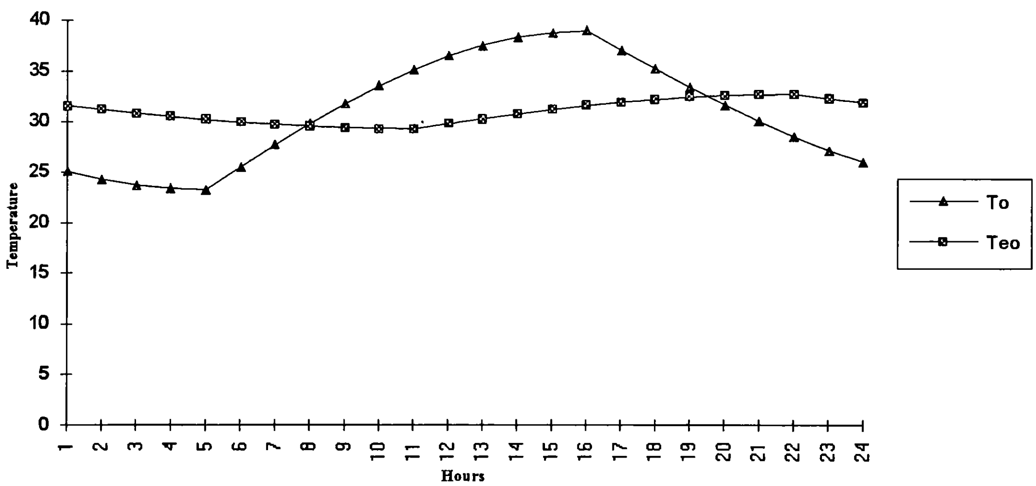


Thermal Properties

U-Value =	0.29 W/m2 C
Admittance	Y= 3.07
Decrement factor	f= 0.21
Surface factor	F= 0.78
Time Lag	Φ = 6.12 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Polyurethane	0.5	0.03	40	1590	1000
3	Hollow Concrete block	0.25	0.38	1200	653	30
4	Plaster, Dense	0.02	0.5	1300	1000	80

Hollow Concrete wall with insulation (cork)

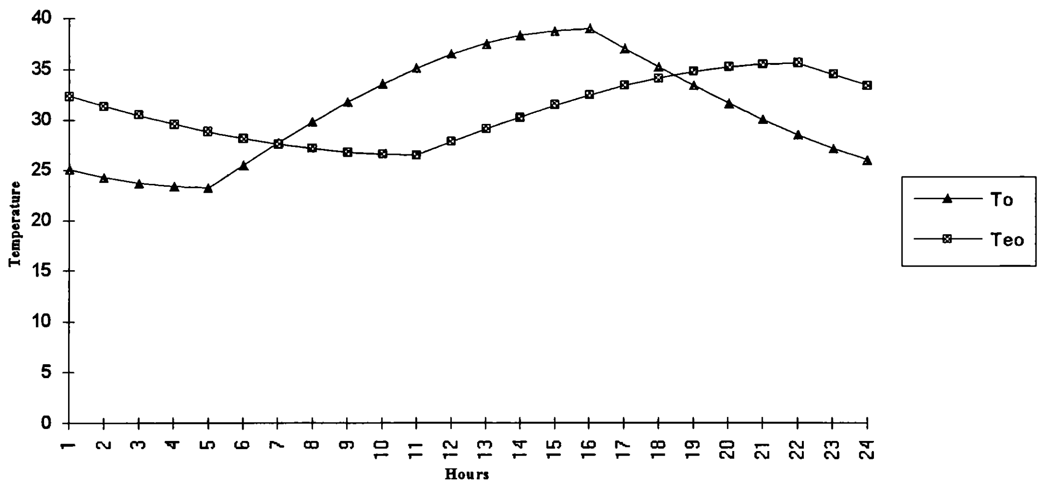


Thermal Properties

U-Value	= 0.34W/m2 C
Admittance	Y= 3.07
Decrement factor	f= 0.22
Surface factor	F= 0.78
Time Lag	Φ =6.12 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Insulation Cork	0.05	0.04	105	1800	40
3	Hollow Concrete block	0.25	0.38	1200	653	30
4	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Hollow concrete block with air-gap

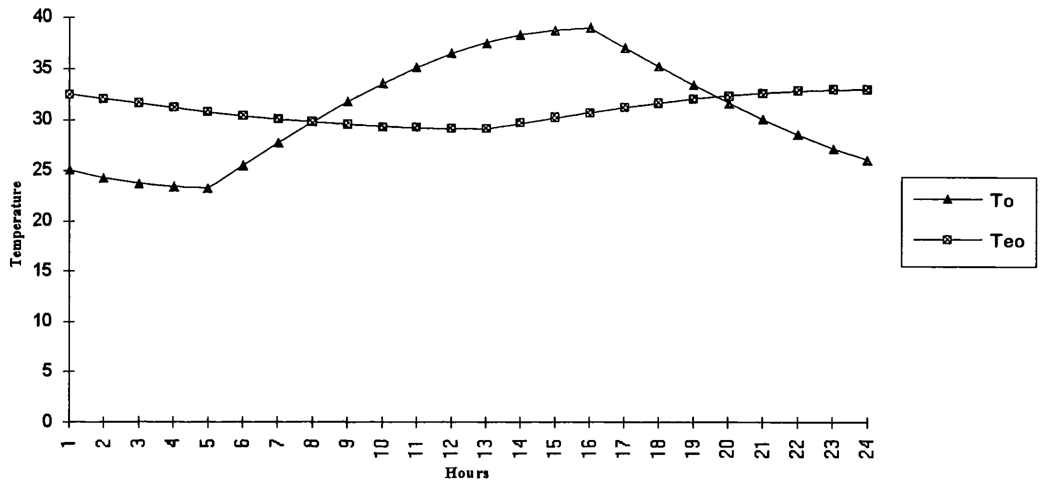


Thermal Properties

U-Value =	0.62 W/m2 C
Admittance	Y= 3.12
Decrement factor	f= 0.58
Surface factor	F=0.78
Time Lag	Φ = 5.6 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Hollow Concrete block	0.1	0.38	1200	653	30
3	Insulation Air Gap	0.1		1.2		
4	Hollow Concrete block	0.1	0.38	1200	653	30
5	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Hollow concrete block with (cork) as insulation.

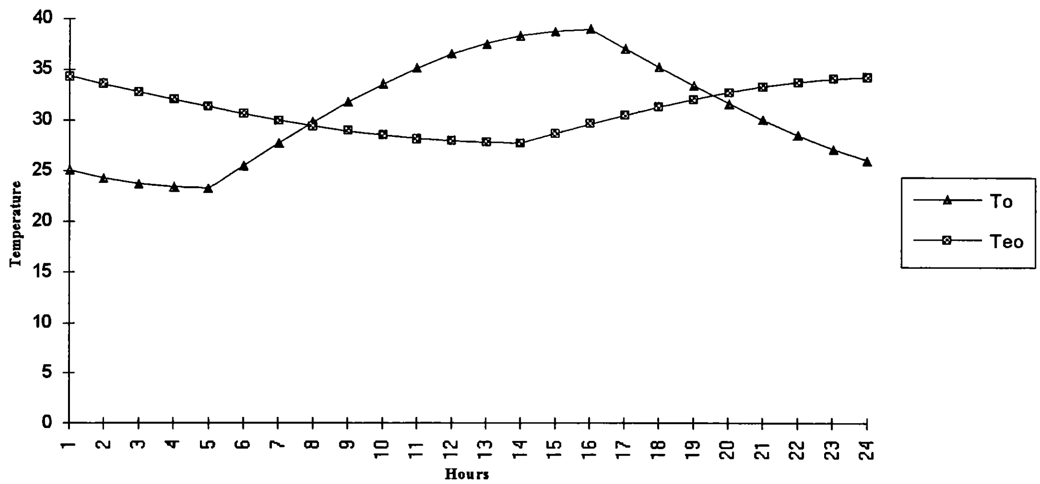


Thermal Properties

U-Value = 0.25 W/m2 C
Admittance Y= 3.25
Decrement factor f= 0.34
Surface factor F= 0.78
Time Lag Φ =8.6 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Hollow Concrete block	0.1	0.38	1200	653	30
3	Insulation Cork	0.1	0.04	105	1800	40
4	Hollow Concrete block	0.1	0.38	1200	653	30
5	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Hollow concrete block with polyurethane as insulation.

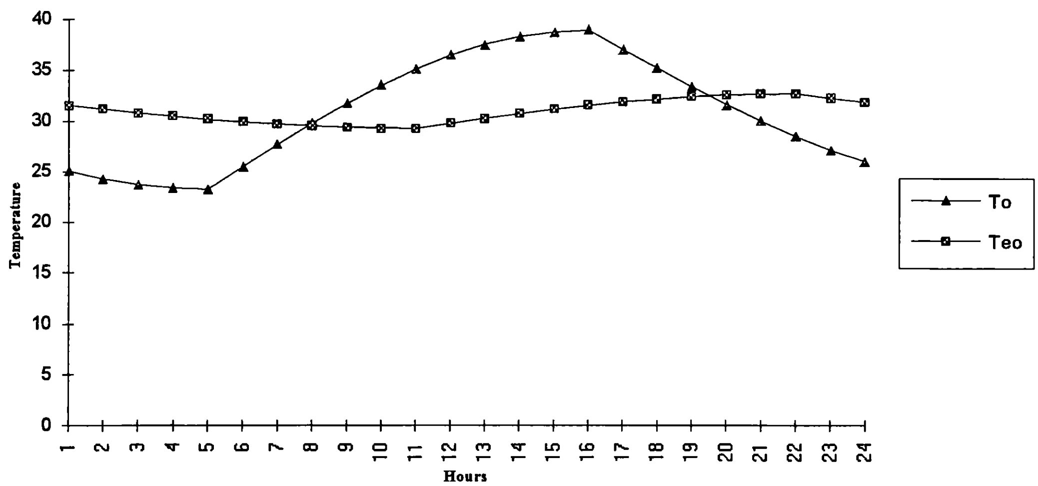


Thermal Properties

U-Value =	0.21W/m2 C
Admittance	Y= 3.32
Decrement factor	f= 0.42
Surface factor	F= 0.78
Time Lag	Φ = 9.3 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Hollow Concrete block	0.1	0.38	1200	653	30
3	Polyurethane	0.1	0.03	40	1590	1000
4	Hollow Concrete block	0.1	0.38	1200	653	30
5	Plaster, Dense	0.02	0.5	1300	1000	80

Single Limestone wall

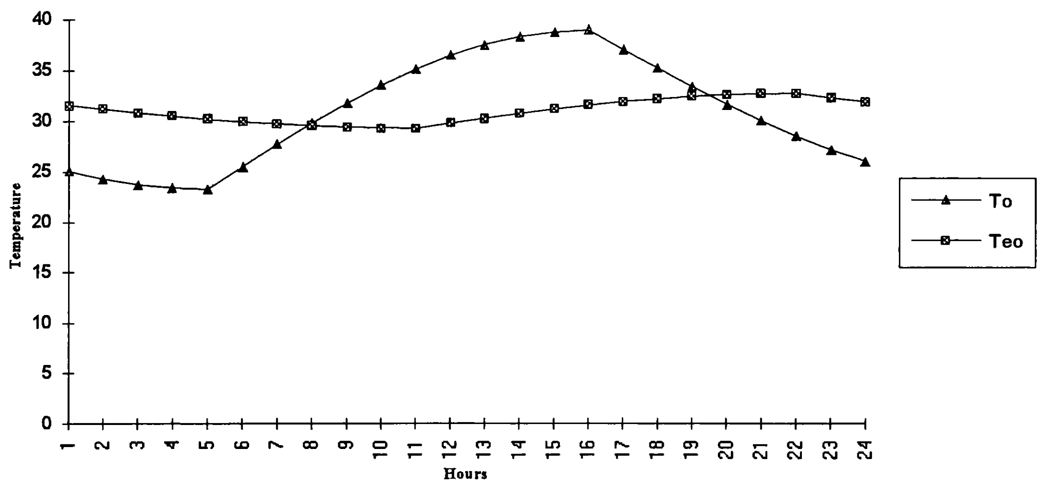


Thermal Properties

U-Value =	2.34 W/m2 C
Admittance	Y= 4.91
Decrement factor	f = 0.36
Surface factor	F= 0.47
Time Lag	Φ = 4.6 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Limestone	0.25	1.5	2180	720	150
3	Plaster, Dense	0.02	0.5	1300	1000	80

Limestone wall with insulation (polyurethane)

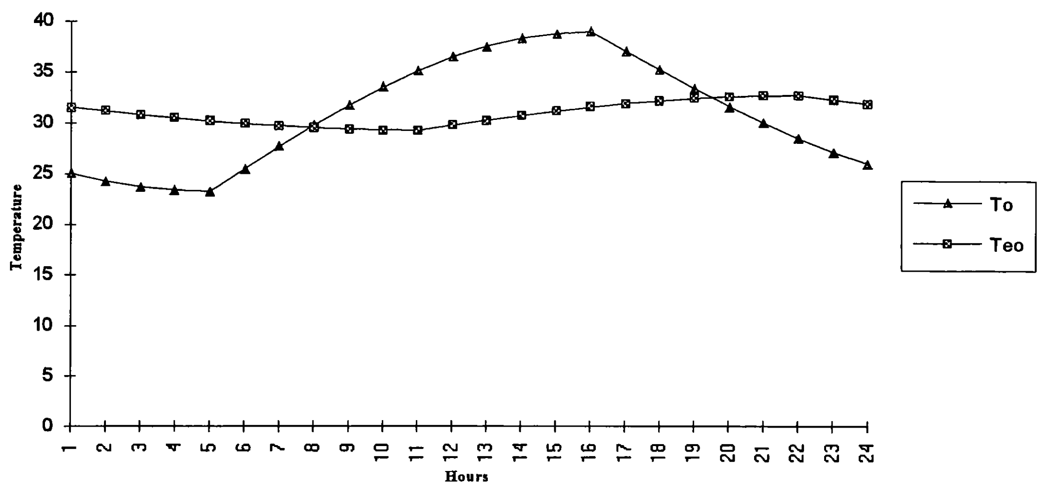


Thermal Properties

U-Value =	0.48W/m2 C
Admittance	Y= 4.9
Decrement factor	f= 0.16
Surface factor	F= 0.46
Time Lag	Φ = 5.5 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Insulation Polyurethane	0.05	0.03	40	1590	1000
3	Limestone	0.15	1.5	2180	720	150
4	Plaster, Dense	0.02	0.5	1300	1000	80

Limestone wall with insulation (cork)

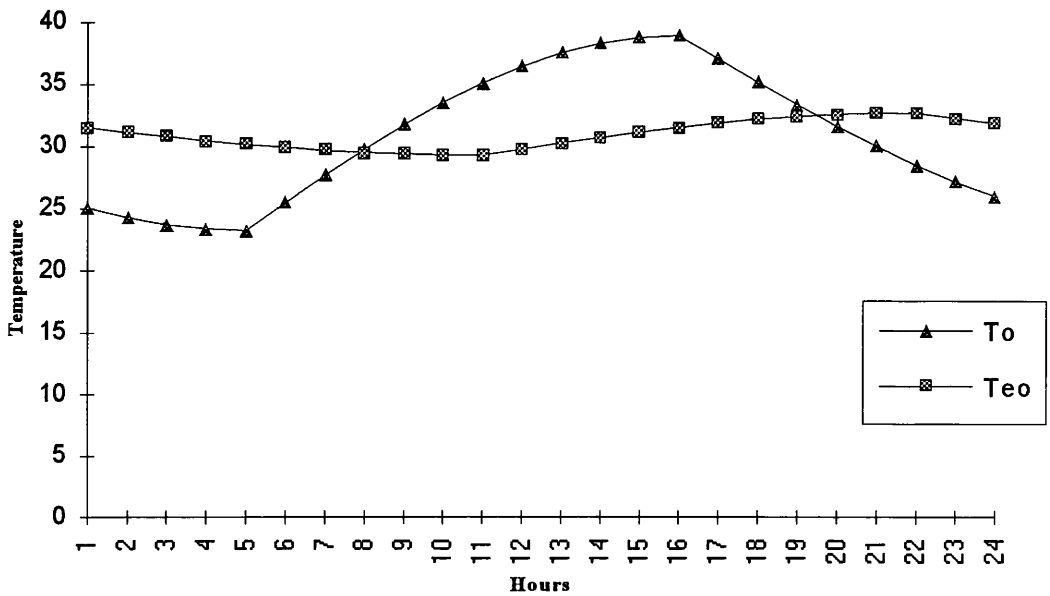


Thermal Properties

U-Value = 0.60 W/m2 C
Admittance Y= 4.95
Decrement factor f= 0.16
Surface factor F= 0.45
Time Lag Φ = 5.39 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Insulation (Cork)	0.05	0.04	105	1800	40
3	Limestone	0.25	1.5	2180	720	150
4	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Limestone with (air-gap)

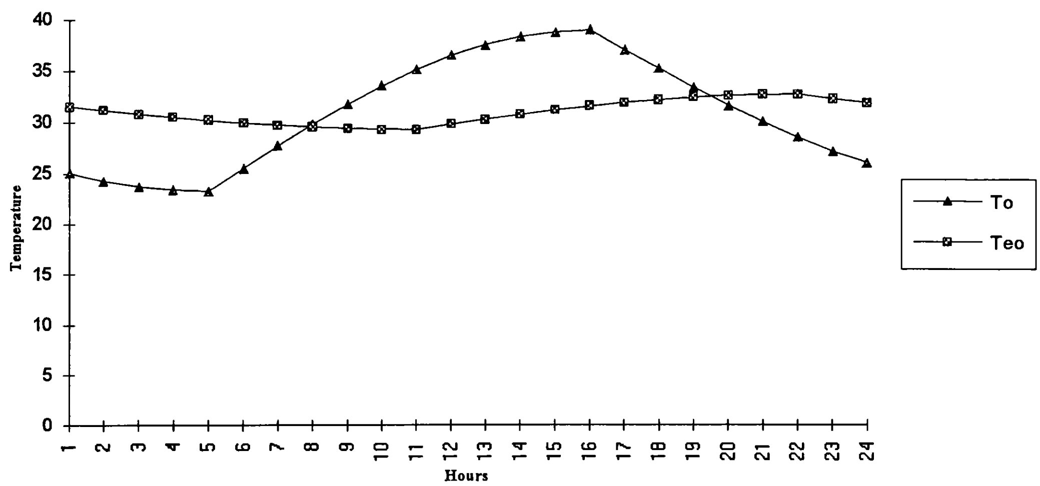


Thermal Properties

U-Value =	1.56 W/m2 C
Admittance	Y= 5.05
Decrement factor	f= 0.21
Surface factor	F= 0.47
Time Lag	Φ = 6.3 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Limestone	0.15	1.5	2180	720	150
3	Insulation (Air-gap)	0.05		1.2		
4	Limestone	0.15	1.5	2180	720	150
5	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Lime-Stone wall with insulation (cork)

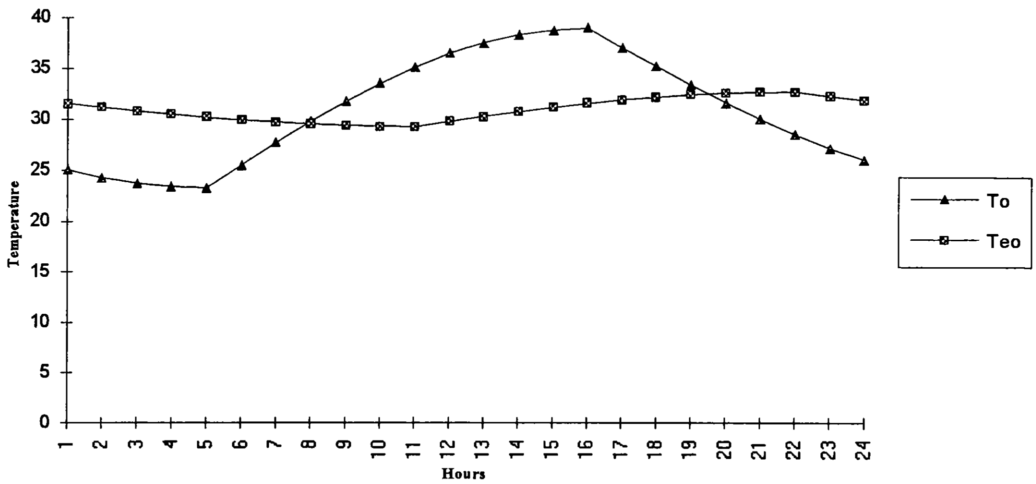


Thermal Properties

U-Value =	0.58 W/m2 C
Admittance	Y= 5.17
Decrement factor	f= 0.12
Surface factor	F= 0.45
Time Lag	Φ = 9.17 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Limestone	0.15	1.5	2180	720	150
3	Insulation (Cork)	0.05	0.04	105	1800	40
4	Limestone	0.15	1.5	2180	720	150
5	Plaster, Dense	0.02	0.5	1300	1000	80

Cavity Lime-stone wall with polyurethane as insulation

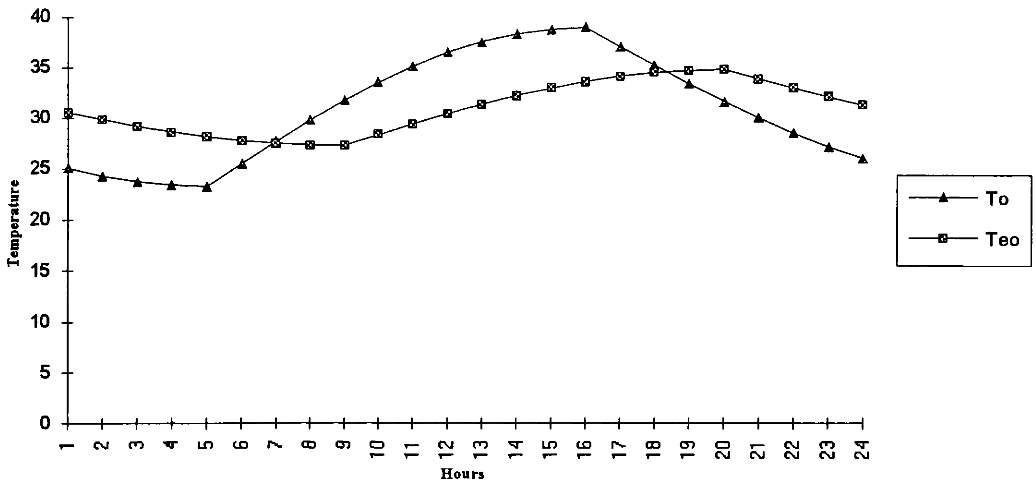


Thermal Properties

U-Value =	0.47W/m2 C
Admittance	Y= 5.24
Decrement factor	f= 0.12
Surface factor	F= 0.45
Time Lag	Φ = 10.07 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Plaster, Dense	0.02	0.5	1300	1000	80
2	Limestone	0.15	1.5	2180	720	150
3	Insulation (Polyurethane)	0.05	0.03	40	1590	1000
4	Limestone	0.15	1.5	2180	720	150
5	Plaster, Dense	0.02	0.5	1300	1000	80

R.Concrete Slab

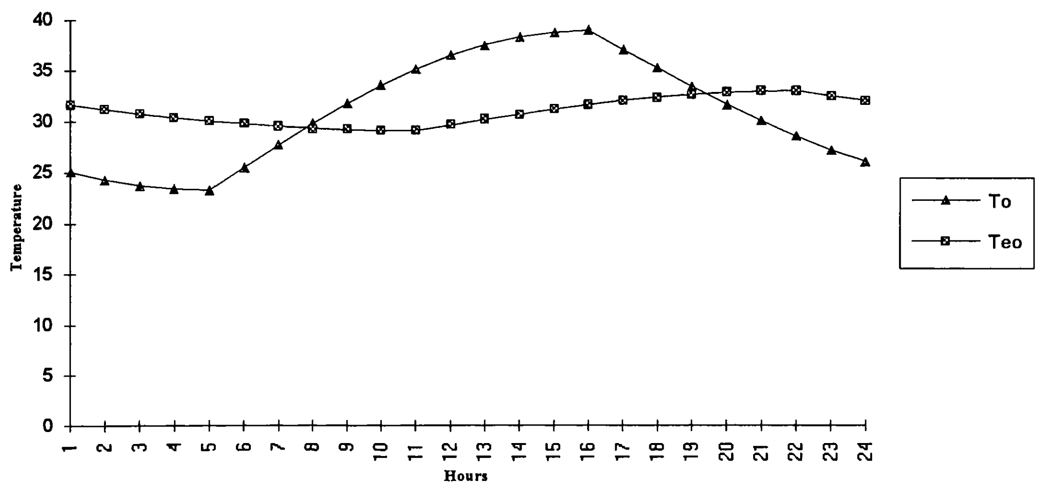


Thermal Properties

U-Value =	1.38 W/m2 C
Admittance	Y= 3.9
Decrement factor	f= 0.48
Surface factor	F= 0.66
Time Lag	Φ = 4.38 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	R.C Concrete slab	0.2	1.1	2100	837	200
5	Cement mortar	0.02	0.38	1200	653	210

R.Concrete with insulation (polyurethane).

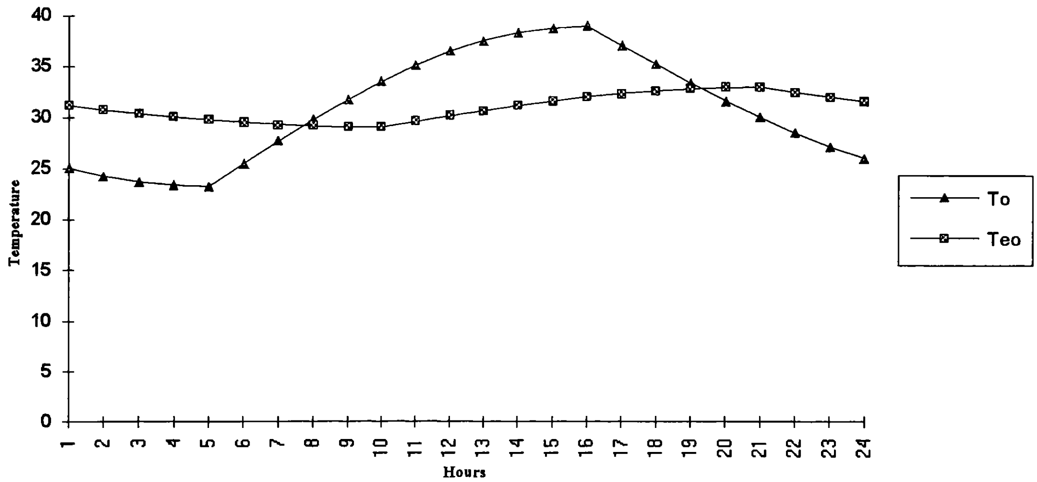


Thermal Properties

U-Value =	.42 W/m2 C
Admittance	Y= 3.96
Decrement factor	f= 0.25
Surface factor	F= 0.64
Time Lag	Φ = 5.6 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	Expanded polyurethane	0.05	0.03	40	1590	1000
5	R.C Concrete slab	0.2	1.1	2100	837	200
7	Cement mortar	0.02	0.38	1200	653	210

R.Concrete slab with insulation (Cork).



Thermal Properties

U-Value = 0.51 W/m2 C

Admittance Y= 3.96

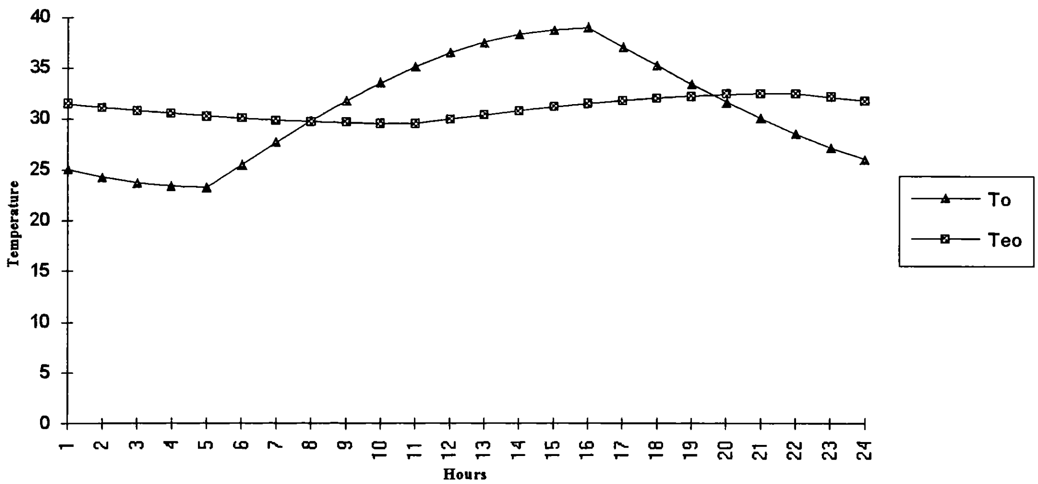
Decrement factor f= 0.25

Surface factor F= 0.65

Time Lag Φ = 5.4 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	Cork	0.05	0.04	105	1800	1000
5	R.C Concrete slab	0.2	1.1	2100	837	200
7	Cement mortar	0.02	0.38	1200	653	210

Hollow Brick , R.Conceret roof.

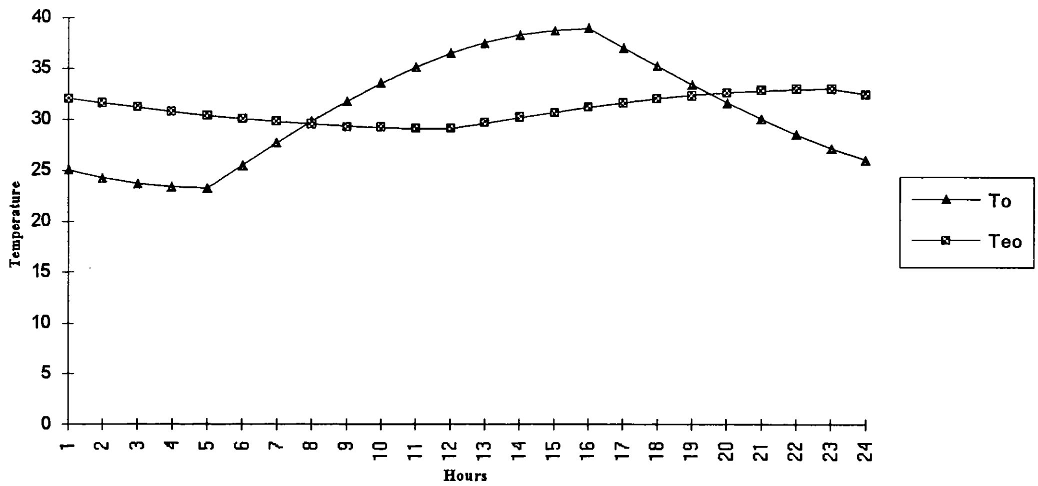


Thermal Properties

U-Value =	0.76 W/m2 C
Admittance	Y= 3.91
Decrement factor	f= 0.19
Surface factor	F= 0.65
Time Lag	Φ = 5.76 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	R.C Concrete slab	0.04	1.8	2242.6	795.47	200
5	Hollow brick block.	0.16	0.36	1500	1000	25
6	Cement mortar	0.02	0.38	1200	653	210

Hollow brick, R.Concrete with insulation (polyurethane).

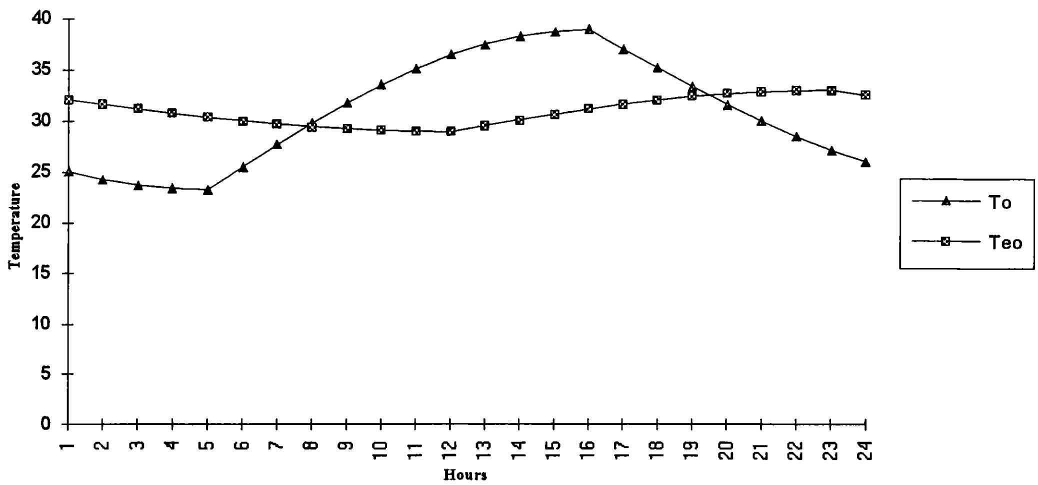


Thermal Properties

U-Value =	0.39 W/m2 C
Admittance	Y= 3.52
Decrement factor	f = 0.25
Surface factor	F= 0.71
Time Lag	Φ = 6.7 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	Expanded polyurethane	0.05	0.03	40	1590	1000
5	R.C Concrete slab	0.04	1.8	2242.6	795.47	200
6	Hollow brick block.	0.16	0.36	1500	1000	25
7	Cement mortar	0.02	0.38	1200	653	210

Hollow Brick ,R.Concrete with insulation (Cork).

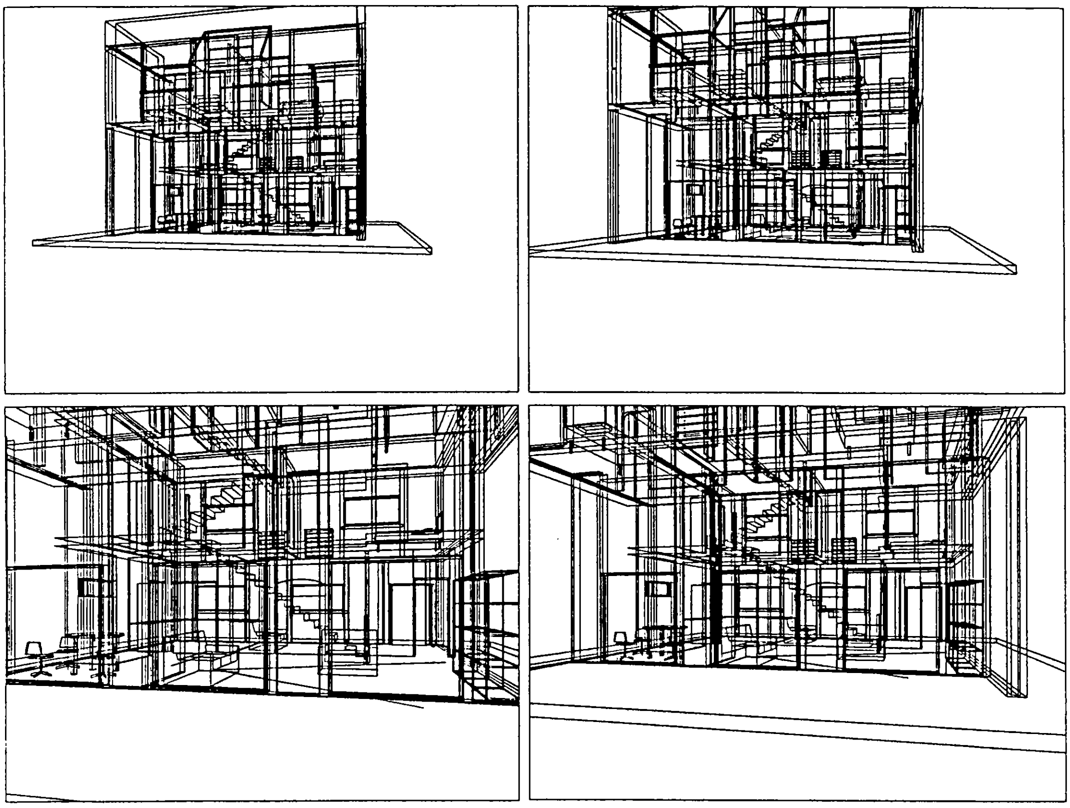


Thermal Properties

U-Value =	0.47 W/m2 C
Admittance	Y= 3.52
Decrement factor	f= 0.26
Surface factor	F= 0.71
Time Lag	Φ = 6.6 hours

Interface	Material	width (m)	Conductivity W/M2 C	Density kg/m3	Specific Heat Capacity J/kg C	Vapour Resistivity GNs/Kgm
1	Terrazzo tiles	0.02	1.1	0.21	837	200
2	Cement mortar	0.02	0.38	1200	653	210
3	DPC	0.01	1.79	1800	1196	200
4	Cork	0.05	0.04	105	1800	1000
5	R.C Concrete slab	0.04	1.8	2242.6	795.47	200
6	Hollow brick block.	0.16	0.36	1500	1000	25
7	Cement mortar	0.02	0.38	1200	653	210

Appendix C



NOTES

PROJECT NAME
Energy efficiency house

PROJECT No
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DRAWING NAME
CAD Model

DWG No
N/A

REV No
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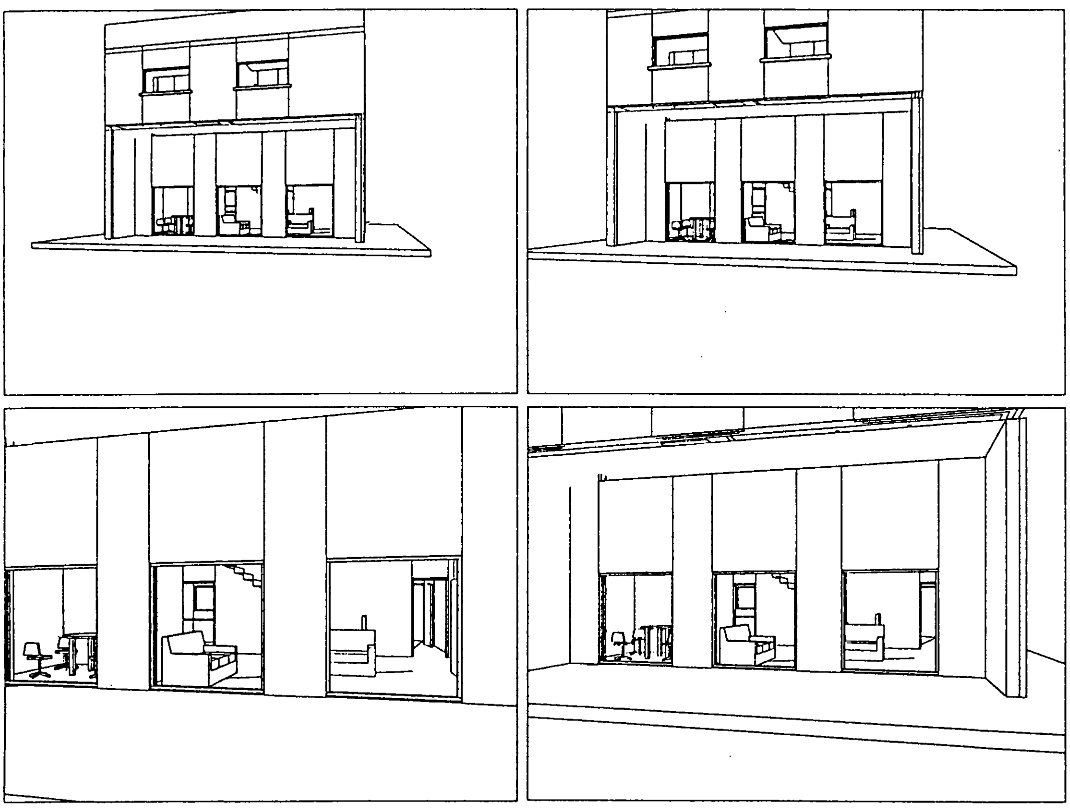

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Energy efficiency house

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CAD Model

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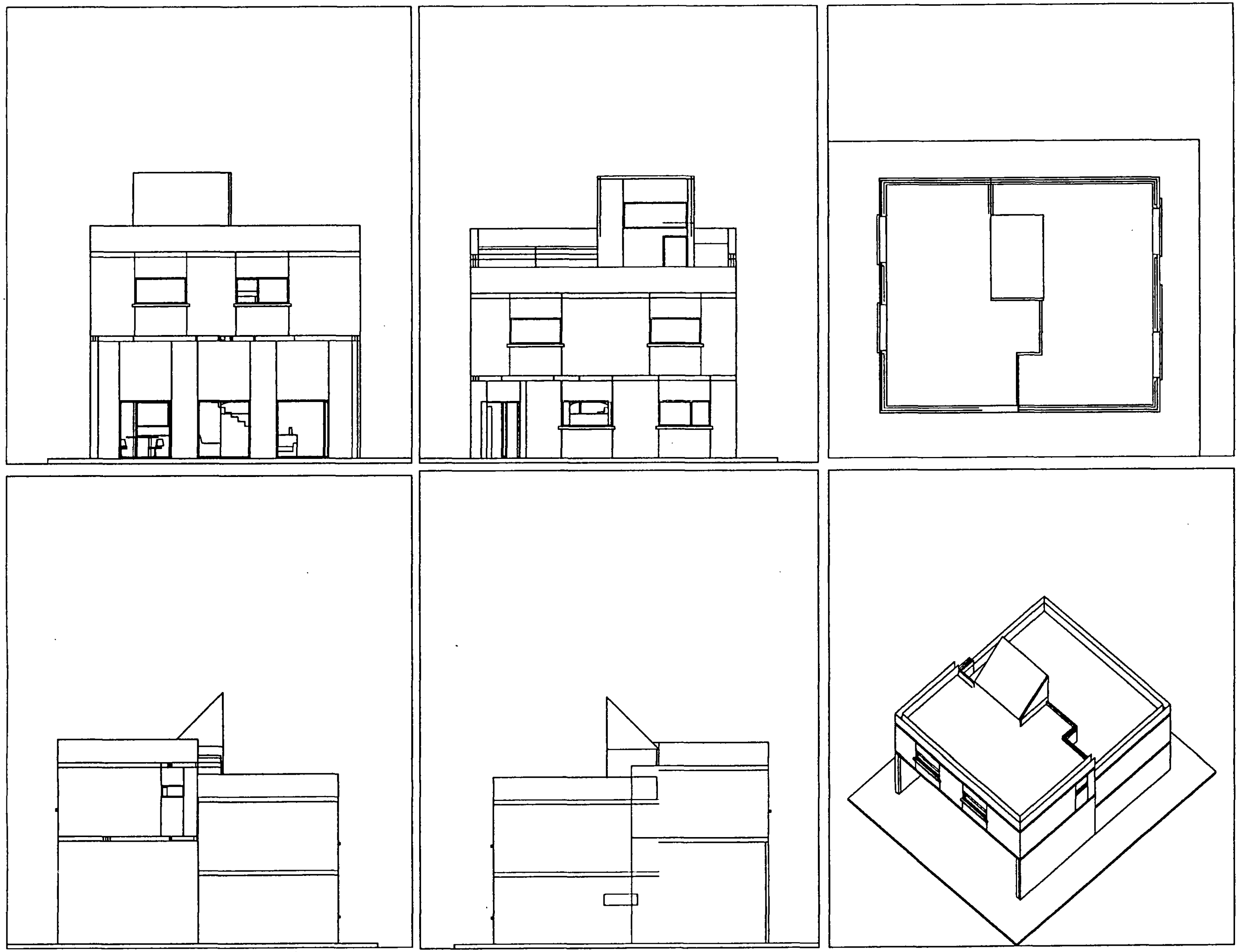

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DWG No N/A	REV No N/A

1
2
3
4
5
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Energy efficincy house
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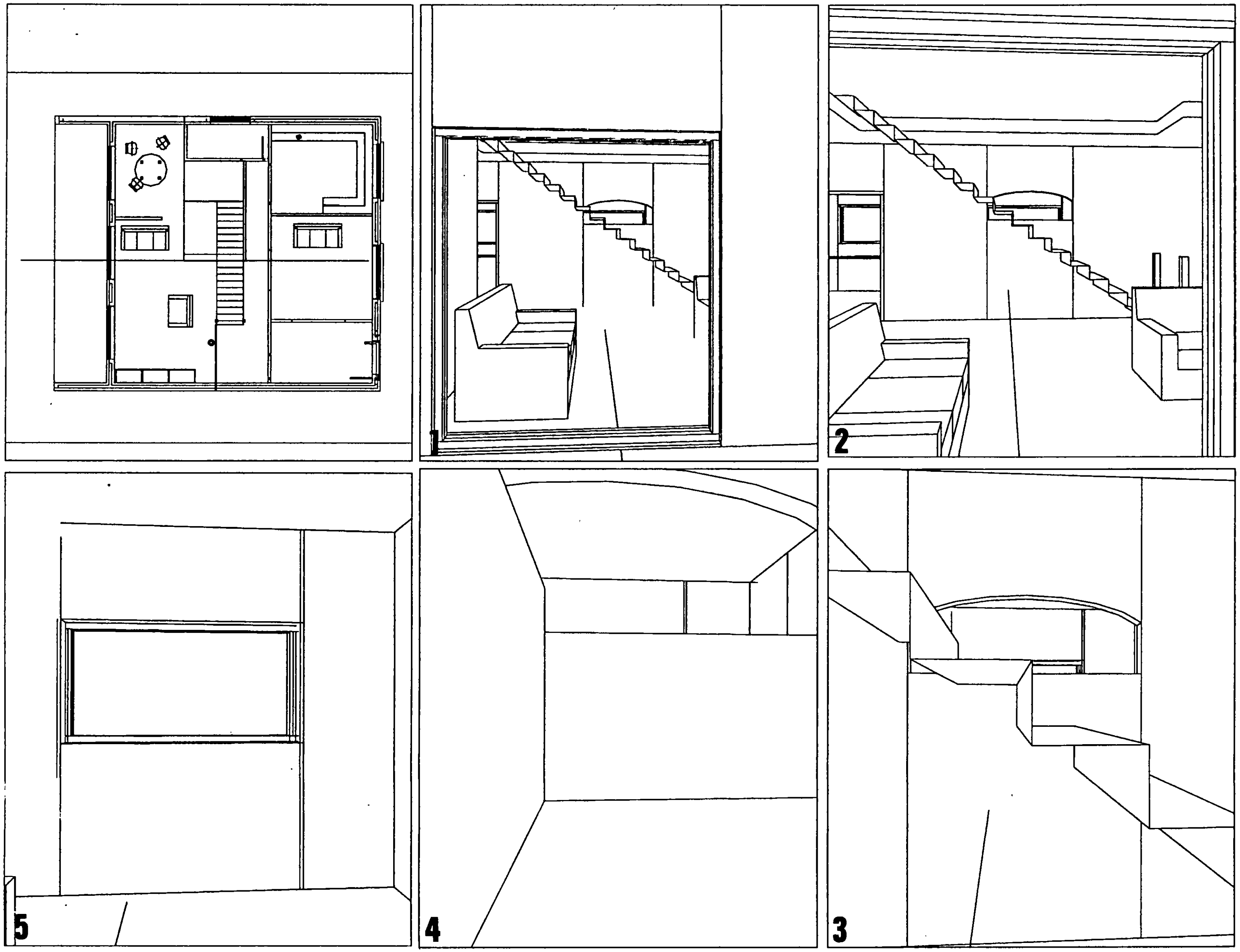

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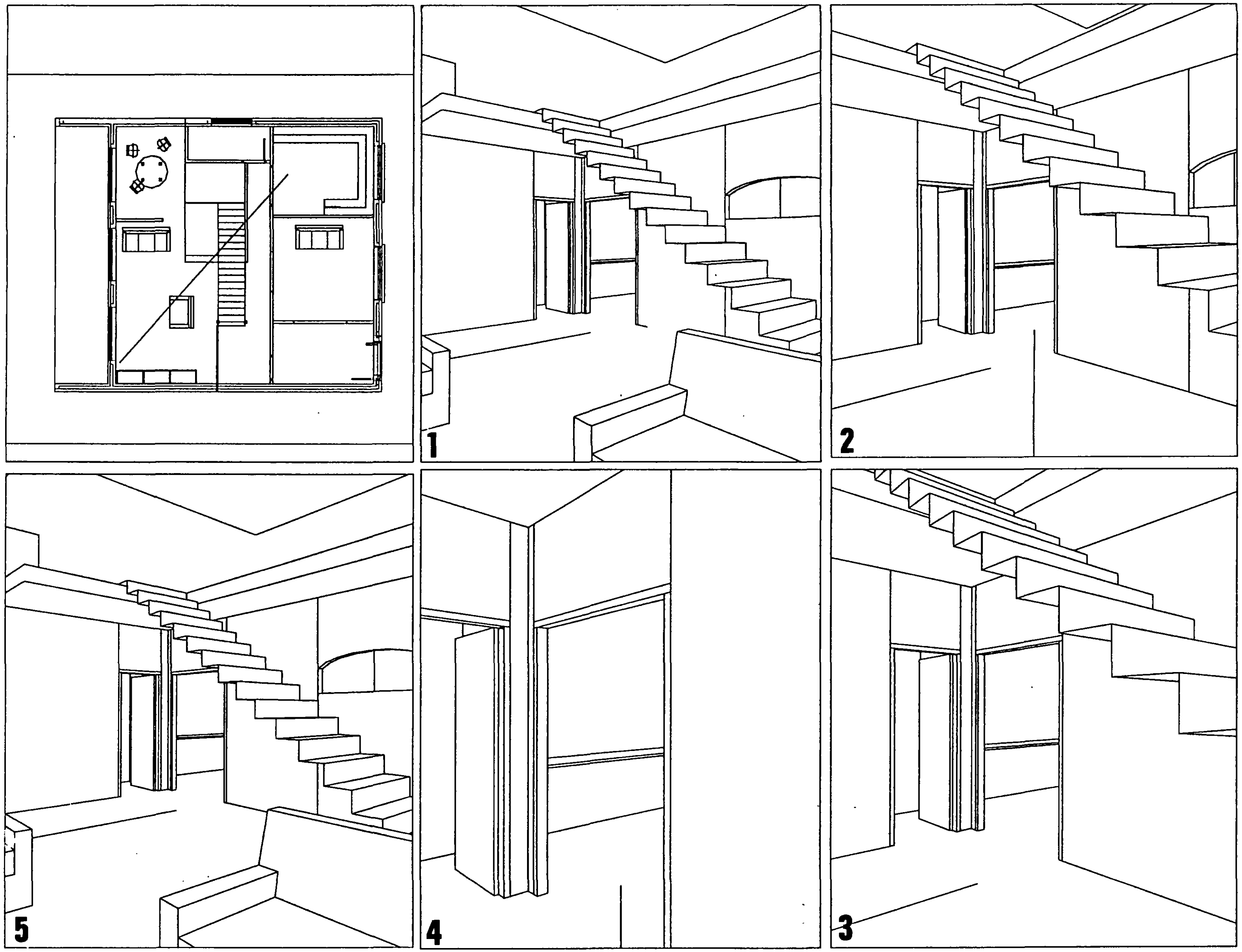

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PROJECT NAME
Energy efficincy house

PROJECT No
N/A

SCALE
1:100

CHK'D
N/A

DRAWING NAME
CAD Model

DWG No
N/A

REV No
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NOTES

PROJECT NAME
Energy efficincy house

PROJECT No
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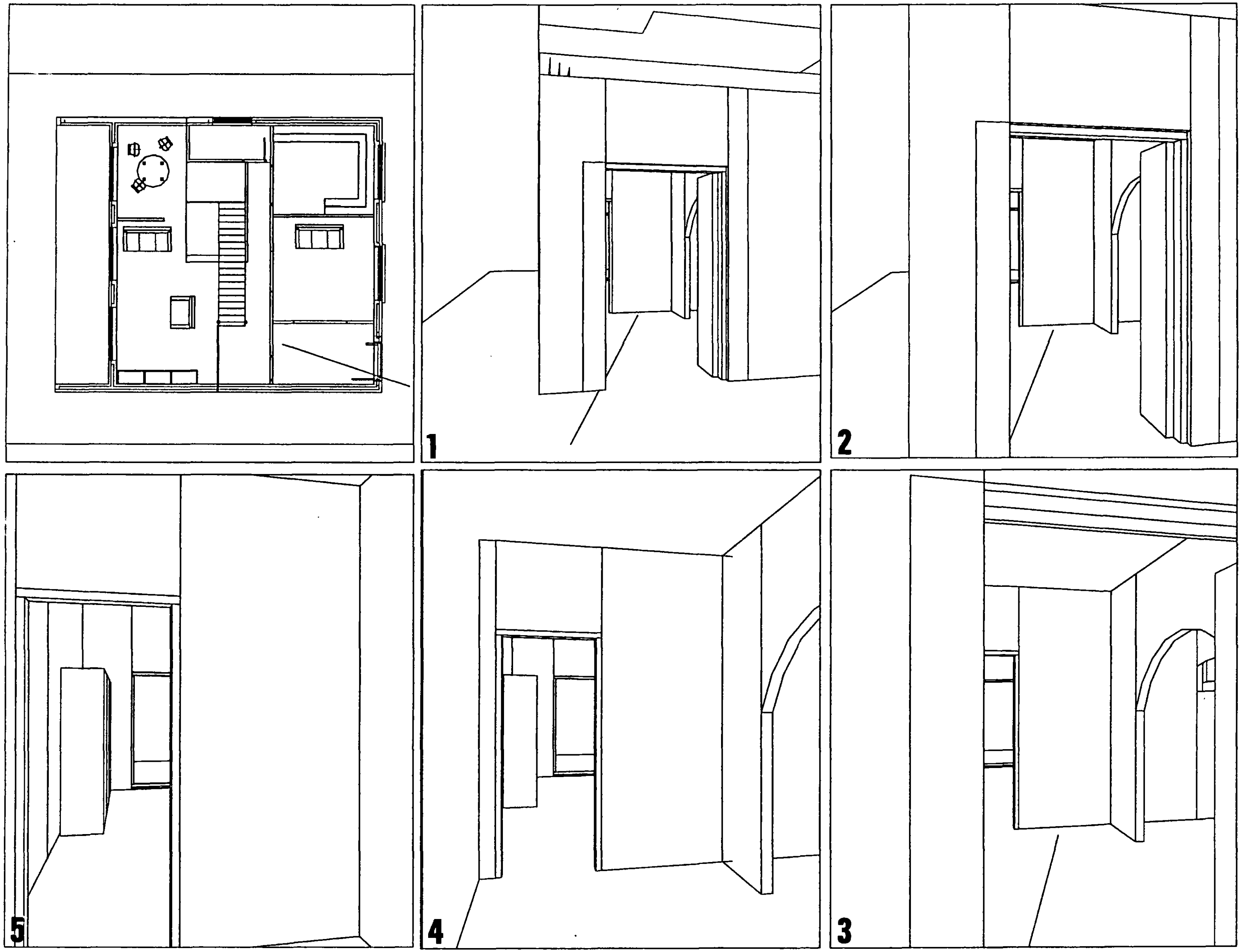
SCALE 1:100	CHK'D N/A

DRAWING NAME
CAD Model

DWG No N/A	REV No N/A



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DRAWING NAME CAD Model	
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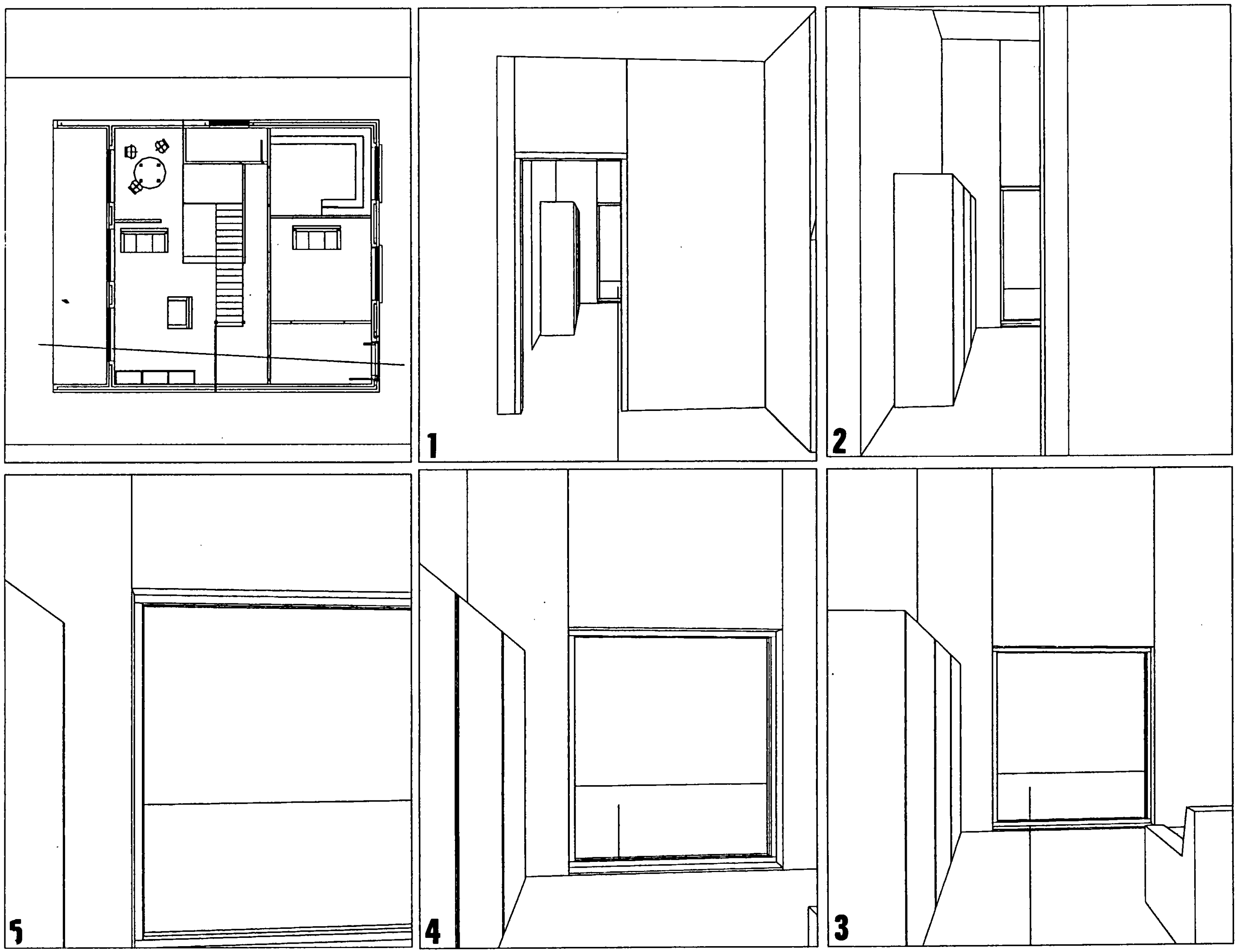

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Energy efficincy house

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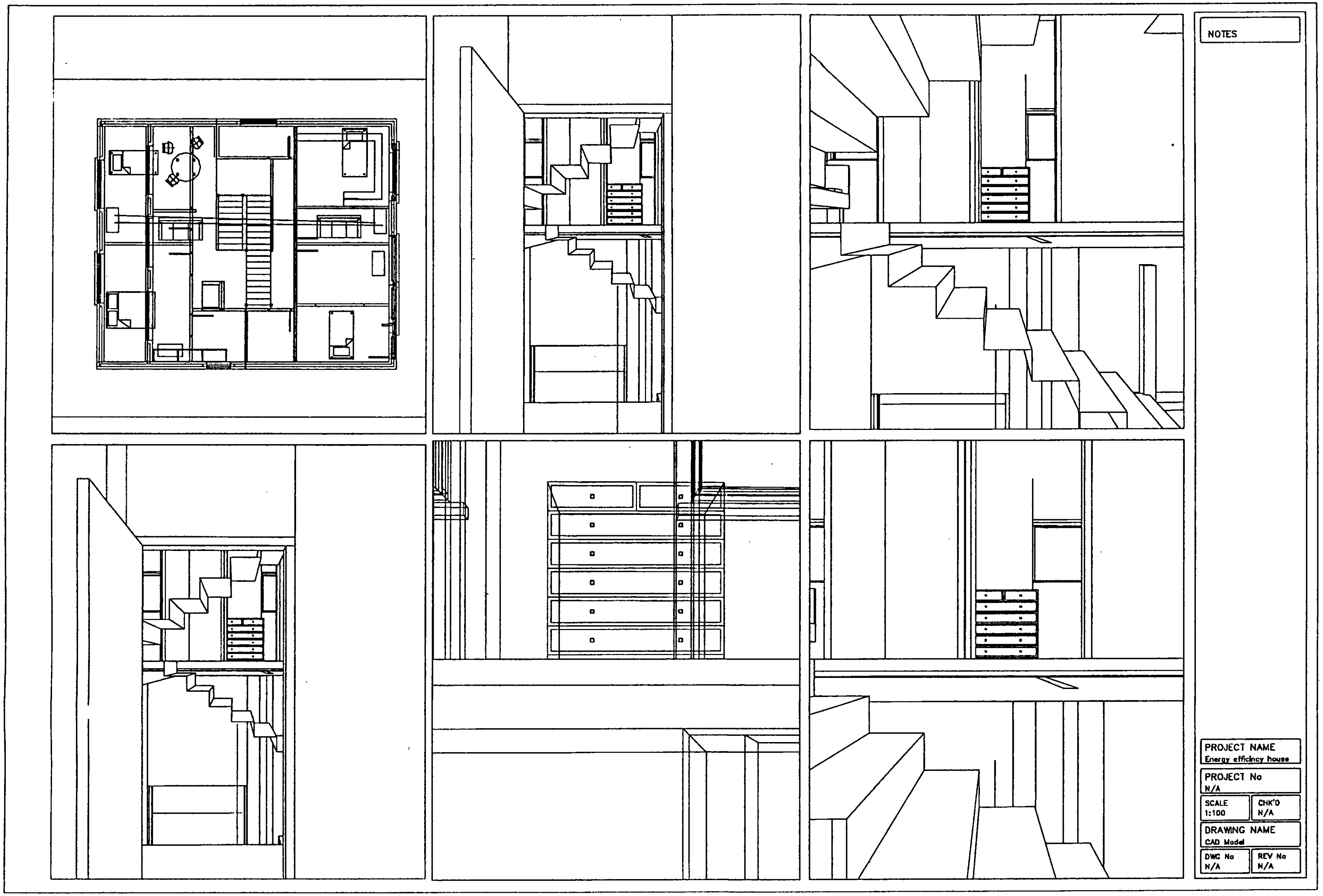
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Energy efficincy house
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SCALE
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DRAWING NAME
CAD Model
DWG No
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REV No
N/A